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NAE TWIN OTTER OPERATIONS IN FIFE 1989

J.I. MACPHERSON

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NAE TWIN OTTER OPERATIONS IN FIFE 1989

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SUBMITTED BY Dr. S.R.M. Sinclair
PRÉSENTÉ PAR
LABORATORY HEAD
CHEF DE LABORATOIRE

AUTHOR J.I. MacPherson
AUTEUR

APPROVED Dr. G.F. Marsters
APPROUVÉ
DIRECTOR
DIRECTEUR

NAE TWIN OTTER OPERATIONS IN FIFE 1989

by

J. I. MACPHERSON

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ABSTRACT

During the summer of 1989, the NAE Twin Otter Atmospheric Research Aircraft was flown in a special three-week extension the NASA-sponsored First ISLSCP² Field Experiment (FIFE-89). Airborne measurements of the fluxes of heat, momentum, water vapour and carbon dioxide were made during 16 low-altitude flights over the FIFE project area in central Kansas. This report documents the Twin Otter operations in FIFE and includes details on the instrumentation, software, flight procedures, atmospheric conditions and analysis methods. Run-average data are presented for all 285 flux runs flown by the Twin Otter in FIFE-89. This report is intended to serve as a working reference for scientists utilizing Twin Otter data either directly or through the FIFE data archive at the NASA Goddard Space Flight Center.

² The International Satellite Land Surface Climatology Project

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NAE TWIN OTTER OPERATIONS IN FIFE 1989

1.0 INTRODUCTION

The First ISLSCP¹ Field Experiment (FIFE) was an international project designed to obtain the data necessary to relate satellite measurements to land surface/atmosphere interactions. The improved interpretation of satellite data is important to both short-term weather forecasts and long-term global monitoring for climate change. Most current global circulation models used for forecasting do not include terms to adequately account for the exchange of energy and mass between the atmosphere and the land surface, and in particular, the vegetation on the surface. FIFE was organized by the National Aeronautics and Space Administration (NASA) to study these processes over one type of vegetation, the tall-grass prairie of central Kansas, with plans to continue in future years to more complex biomes such as the wetlands and boreal forests.

Airborne measurements of the fluxes of heat, momentum, carbon dioxide and water vapour provide an essential link in relating small-scale ground-based measurements to the large scale estimates provided by satellites. With considerable experience in the airborne measurement of these fluxes, the NAE was one of the Canadian agencies that participated in FIFE in 1987, using the NAE Twin Otter atmospheric research aircraft. The Twin Otter also represented the only available system capable of making airborne measurements of the flux of carbon dioxide. This experiment presented an opportunity not only to contribute to the FIFE objectives, but also to continue flux studies in an area of uniform vegetation with enhanced surface and satellite observations. Some of the specific Canadian objectives in FIFE were:

- to compare the Twin Otter measured fluxes with those determined by several surface sites and other instrumented aircraft.
- to relate airborne flux estimates to run length, altitude, and environmental parameters such as vegetation type, temperature, wind speed, solar radiation, atmospheric stability and crop stress.
- to study the use of aircraft for regional observations of fluxes and relate these measurements to satellite radiance data.
- to attempt to infer vegetation growth rates from airborne CO₂ and water vapour flux measurements.

¹ The International Satellite Land Surface Climatology Project

In 1987, the first year of FIFE, 150 scientists, six aircraft and five satellites were involved in the coordinated acquisition of radiometric, atmospheric and surface biophysical data sets over the 15 x 15 km test site near Manhattan, Kansas. A continuous year of monitoring observations (meteorological, satellite and surface measurements) was punctuated by four intensive field campaigns (IFC's), lasting a total of 57 days, during which most of the scientists and the aircraft were working at the site. The NAE Twin Otter participated in three of the IFC's, flying a total of 42 project flights to measure the fluxes of heat, momentum, water vapour and carbon dioxide. Twin Otter FIFE data have been digitally archived at the NASA Goddard Space Flight Center, and have been analyzed and presented in a number of reports and papers (References 1 to 12) .

Analysis of all FIFE results from the many data sources indicated some significant shortcomings in the data set. In particular, no transition from wet to dry soil conditions was observed during any of the IFC's, and no reliable data on the separate contributions to the *net* CO₂ flux were collected. As a result, it was decided that most participants would return to the FIFE site for one additional IFC in the summer of 1989. The field phase of FIFE-89 ran from July 24 to August 12, during which the NAE Twin Otter flew 16 project flights. Data from these flights have been processed by NAE and digitally archived at the NASA Goddard Space Flight Center.

The purpose of this report is to supplement the archive data by documenting the important details of the Twin Otter operations in FIFE-89, as was done in Reference 1 for the 1987 FIFE operations. This will include specific information on the instrumentation, software, recorded parameters, flight operations, analysis procedures and the format for the data archive. A description of each flight will be given which will include instrument status, meteorological conditions, tephigrams and flight track plots. *This report presents relatively more data than the 1987 report.* For example, a table is included which presents run average data, including fluxes, for all 285 data runs flown by the Twin Otter in FIFE-89.

2.0 CANADIAN PROGRAM

Reference 1 summarizes the history of the development of the NAE Twin Otter as a platform for gaseous flux measurement, and the steps leading up to participation in FIFE in 1987. The following organizations and scientists were directly involved in the Canadian Twin Otter operations in FIFE-89.

- NRC/NAE Flight Research Laboratory (J. I. MacPherson).
 - signed memorandum of Agreement with NASA and led Canadian team in participation in FIFE
 - own and operate Twin Otter aircraft
 - on-board scientist, technician and flight crew; data analysis

- Agriculture Canada, Land Resource Research Centre (R. Desjardins).
 - provide CO₂/H₂O analyzer; collaboration in analysis
- McGill University, MacDonald College Dept. of Renewable Resources (P. Schuepp).
 - on-board scientist; collaboration in analysis

In addition, the Atmospheric Environment Service (B. Goodison) provided the PRT-5 sensor for measuring ground surface temperature beneath the aircraft. The Canada Centre for Remote Sensing (J. Cihlar) will participate in some of the data analysis, in particular relating measured fluxes to satellite remote sensing data.

Funding for the direct operating costs of the Twin Otter aircraft and the associated travel costs of the support staff was provided by NASA.

3.0 INSTRUMENTATION

Figure 1 is a schematic diagram of the Twin Otter showing the mounting locations of the instruments flown in FIFE-89. Table 1 lists the sensors, type of output signal, and the label of the associated variables in the aircraft software.

An exhaustive description of the Twin Otter instrumentation will not be given here; this is available in References 13 to 15. Rather, the sections below will focus on *changes and improvements* to the instrumentation from the configuration used in the 1987 FIFE experiment, which was described in detail in Reference 1.

3.1 Air Motion

The Twin Otter is instrumented to measure the three orthogonal components of atmospheric motion over a frequency range of 0 to 5 Hz. The true air motion is derived in aircraft axes from the vector difference between the air velocity relative to the aircraft and the aircraft 'inertial' velocity relative to the ground (strictly speaking, the rotating earth is not an inertial frame of reference, but for ease of expression the term 'inertial' in this report will mean 'relative to the earth').

Air motion relative to the aircraft is measured by a nose-mounted gust boom incorporating a Rosemount 858 5-hole probe (Fig. 1). This device and the associated pressure transducers measure static pressure (altitude), dynamic pressure (airspeed) and the angles of attack and sideslip. A second altitude/airspeed system employs a separate set of pressure transducers connected to the

fuselage-mounted pitot and static ports used for the flight instruments. The only change made to this system since 1987 was the application of slightly improved position error corrections, as detailed in Reference 15. These corrections are required for all aircraft to account for systematic pressure disturbances caused by the presence of the aircraft.

A major change has been made in the measurement of the inertial velocity of the aircraft. For the 1987 FIFE, this was measured using a complementary filtering technique, with the high-frequency contribution from integrated accelerometer and rate gyro signals, and the low-frequency contribution from a 3-axis Doppler radar. In 1989, an alternative inertial velocity was recorded from a Litton LTN-90/100 Inertial Reference System (IRS). Although this device was installed and evaluated in 1987, and discussed in Section 3.2 of Reference 1, it was *not* used in the 1987 FIFE data analysis. For the FIFE-89 data reported here, the IRS provided the inertial velocity for all the project flights, with the exception of the first.

Although the Litton IRS is now considered the primary instrument on the aircraft for the measurement of the inertial velocity, it was decided, for FIFE-89 at least, to retain the earlier complementary-filtered routine in the airborne software to serve as a back-up in case of IRS failure. Therefore, on the NAE Twin Otter, the on-board LSI-11/73 microprocessor currently computes *three* sets of winds, differing primarily in the means used to determine the inertial velocity. They are the following:

- 1) **NAE/DOP winds:** This uses a complementary filtering routine where the low frequency contribution to the inertial velocity is from a 3-axis Decca Doppler radar, and the high frequency components are from an NAE-assembled package of accelerometers and rate gyros. Winds are first computed in aircraft body-fixed axes, then resolved into earth axes (i.e., the locally level geographic frame of reference aligned with true north and east) using the signals from the aircraft attitude gyro and C-12 compass.
- 2) **Litton winds:** The true airspeed (TAS) vector is resolved into earth-fixed axes using the attitude angles and heading from the LTN-90 IRS. The 3-axis inertial velocities from the IRS are then subtracted from the TAS components to derive the 3-axis winds. This is the method used on most atmospheric research aircraft. It is subject to approximately 1 ms^{-1} errors in the horizontal components due to IRS drift caused by the Schuler oscillation phenomenon (Reference 16).
- 3) **Lit/DOP winds:** This is similar to (1) above, except that the accelerometer, rate gyro, attitude and heading measurements all come from the LTN-90 IRS rather than the NAE package.

Further details on these wind computation methods are given in References 15 and 17. In summary, the method used for all but the first flight in FIFE-89 is that labelled above as **Litton winds**. For the first flight, the NAE/DOP winds were used, due to an IRS alignment error (thus effectively demonstrating the value of the back-up system).

3.2 Position

As in 1987, the Twin Otter carried an ARNAV Model R-40-AVA-100 Loran-C navigation system, which was used for flying specific tracks and for recording aircraft position. There were two sources of error in the position recorded from the Loran-C: (1) an offset in which the recorded position was about 0.5 nautical miles northeast of the actual position, and (2) a lag in which the recorded position trailed the actual position by about 0.27 nautical miles. These are discussed more fully in Section 3.3 of Reference 1.

In FIFE-89, aircraft position data were also available from the LTN-90 Inertial Reference System. This system is subject to the Schuler oscillation in which the indicated position can drift in error up to approximately one nautical mile per hour. For operations in a small area such as the FIFE site, this is a relatively large error. Consequently, the archive data and the flight track plots shown in Figure 8 are based on Loran-C position data, as in 1987.

3.3 Carbon Dioxide and Water Vapour

The fast-response concentration measurements required for the CO_2 and H_2O flux calculations were made by the ESRI infrared gas analyzer developed by the Agriculture Canada. The test section of the analyzer was mounted within a large duct that captured flow above the aircraft, entered the cabin through the roof, and passed through the rear of the cabin to exit through the floor (Figure 2). The system had a flow rate of approximately 300 litres/sec. The duct was also instrumented for the measurement of the airspeed, temperature and density of the sampled air, in order to calculate the CO_2 and H_2O mixing ratios. The ESRI analyzer had an effective frequency response of 15 Hz. Its operation in the 1987 FIFE project was discussed at length in Reference 1. Prior to FIFE-89, minor software and hardware changes were made to the analyzer to eliminate occasional dropouts in its digital output. Improvements were also made to the mounting structure of the analyzer test section, and the electronics were housed in a new rack (Figure 2).

Data from the ESRI analyzer are suitable for use with the vertical gust velocity and the eddy correlation technique to derive fluxes. However, it is not well suited to the measurement of absolute concentrations of CO_2 and water vapour, for its sensitivity can change a few percent during flight because of dirt accumulating on its mirrors. For this reason, a second, slower-response analyzer was installed in the Twin Otter for FIFE-89. This was a LI-COR LI-6251 CO_2

analyzer, which was mounted in the new rear rack (Figure 2), with its sample air drawn from the duct via a 3/8-inch plastic tube.

The LI-COR analyzer was also subject to sensitivity changes due primarily to pressure variations associated with altitude changes. Therefore, a system was designed and built to provide a self-calibration feature to be operated prior to most data runs. This was initiated by a button on the cockpit console, which activated a Campbell Scientific 21-X Data Logger that controlled a system of relays. These relays directed the flow of two reference gases to the LI-COR analyzer, first nitrogen (zero CO₂) for a timed period (usually about 10 seconds), followed by a second sample containing a ground-calibrated reference concentration of CO₂. A flag bit was also recorded on the NAE event marker which was used to identify this calibration sequence during data playback. Using the recorded LI-COR signals and the known reference gas concentrations, a subroutine in the playback program could then calculate a corrected sensitivity factor for the LI-COR data for the subsequent run.

During FIFE-89, this self-calibration sequence was initiated just prior to the start of most data runs, after the aircraft had been levelled at the correct altitude for the run. In the majority of cases, the system worked well, giving fairly consistent sensitivity changes, which were usually only about 1 to 3 percent. However, on a significant number of runs, the recorded signals associated with the calibration gases did not stabilize at the expected reference levels, so the sensitivity factors were considerably in error for these runs. It could not be determined what caused this, although pressure effects, back-flow and faulty relays were considered. Because the self-calibration technique did not reach the level of reliability desired, it was decided to *not* apply the sensitivity correction factors to the LI-COR data in the ground analysis of the FIFE-89 data. Further investigation of this self-calibration system will be undertaken when the aircraft is next configured for flux measurement.

3.4 Temperature and Dew Point

In the 1987 FIFE project, total temperature was measured by a Rosemount fast-response 102DJ1CG heated probe mounted on the port side of the aircraft nose (TTF, Table 1). In subsequent data analyses, it appeared that the aircraft-measured sensible heat fluxes were lower than expected, when compared with surface measurements. This was also the case for the other two flux measuring aircraft in the 1987 project. Aircraft to aircraft intercomparisons showed very good agreement (Section 8.3, Reference 1), indicating that the problem may be common to all aircraft, possibly as a result of flow distortion around the nose.

To investigate this possibility, a second identical temperature probe (TTNB) was mounted on the noseboom fairing, which was closer to the 858-probe location where the gust velocity was measured. For all FIFE-89 data

runs, the sensible heat flux was computed using potential temperatures derived from both probes. Comparison of the results indicates that heat fluxes from the new probe were usually 5-10 percent *lower* than those from the fuselage-mounted probe. Mounting location does appear to make a difference in the fluxes, although not in the direction anticipated. Further investigation is required. The analyzed data archived for FIFE-89 use the sensible heat fluxes from the fuselage probe, as was done in 1987.

Dew point temperature was measured using an E, G and G Model 137 Cambridge dew point sensor mounted on the starboard side of the Twin Otter nose. As an experiment, it was decided to compute a second H_2O flux using dew point data for comparison with the flux measured by the ESRI fast-response gas analyzer. The equations used are detailed in Reference 15. Although the dew point analyzer has a time constant in excess of a second, for most FIFE-89 runs the computed flux was surprisingly close to that from the fast-response analyzer, i.e., usually within 10 percent. These results are only achieved, however, when the gust velocity is lagged by an appropriate number of data sampling time intervals (i.e., 20 which corresponds to 1.25 seconds), as explained in Section 4.2.2 below.

3.5 Radiometers

The same four radiation-measuring sensors used in 1987 (Section 3.7, Reference 1) were mounted on the Twin Otter for FIFE-89. There were no significant changes to either the downward Eppley-2 pyranometer, which measured reflected radiation, or the Skye Industries Vegetation Greenness Indicator.

The incident radiation was again measured with a Kipp and Zonen CM-11 pyranometer with a 305-2800 nm spectral range. The signal conditioning card for its input to the data recording system was not calibrated until July 29, 1989, that is, after Flight 03. As a result, the recorded signal was in error by about 5 percent for Flights 01-03. The playback software was modified to apply a correction for these flights, so that the analyzed data in the archive and listed below are not subject to the signal conditioning error.

For FIFE-89, a more accurate calibration of the PRT-5 infrared surface temperature radiometer was performed. A black metal cone was fabricated which was immersed in a well-mixed water bath and mounted under the PRT-5 sensor for calibration. This calibration was not done until after Flight 03, however, so software corrections were applied in the analysis program for Flights 01-03.

3.6 Event Marker

A multi-level event marker was recorded with a 16-bit word, which also incorporated the positions of eight function switches on the cockpit console. These were used to set flags in the airborne and playback software. Table 2 summarizes the event marker configuration for FIFE-89. There were only two changes from that used in 1987. Bit-5 (function switch #5) indicated which of the two temperature measurements (Section 3.4) was used in the true airspeed calculation. Bit-11 was the flag indicating that the LI-COR CO₂ analyzer was in its self-calibration cycle.

3.7 Microprocessor and Displays

The Twin Otter carries two microprocessors, an LSI-11/73 performing real-time computations of the wind, approximate fluxes, etc., and a DEC Falcon which manages the recording of the sensor outputs and the computed parameters. The two are connected by a Communication Interface Board (CIB). Full in-flight interaction with the main processor is provided by a console-mounted keyboard in the cockpit, with programs loaded from a dual floppy disk unit. Alpha-numeric data are presented on 12x40-character plasma display units in the cockpit and rear cabin. The LSI-11/73 replaces a slower LSI-11/23 which was used in 1987, thereby allowing the computation of the three separate winds (Section 3.1) and more accurate, real-time estimates of the fluxes (Section 4.1).

3.8 Data Recording System

The Twin Otter data acquisition system utilizes a CDC streamer tape drive, which has a capacity of 70 Mbytes on a 15x10 cm compact cartridge. The recording format is under computer control and is therefore very flexible. For FIFE-89, 64 parameters were written in 16-bit binary words at a rate of 16 samples per second. Data were written in 4096-word records, each representing 4 seconds of data. A header block at the start of each file provided flight information, a parameter identification list and scale factors with which to convert the recorded bit levels to engineering units.

All parameters which originate as analog signals (see Table 1) undergo anti-alias low-pass filtering on initial signal conditioning. Second order Butterworth filters are used with a breakpoint set to 5 Hz. At a true airspeed of 60 ms⁻¹, the minimum resolvable wavelength of the Twin Otter measurements is therefore about 12 m.

Table 3 presents the recorder buffer used in FIFE-89, which is considerably different from that used in 1987. It includes the parameter name used in the software, its position in the recorder buffer, its units and a brief description. Conversion of the recorded decimal bits to engineering units is accomplished by dividing by the indicated scale factor. The scale factor is essentially the inverse of the recording resolution.

4.0 SOFTWARE

4.1 Airborne

Several changes were made to the airborne software since 1987 to take advantage of the faster LSI-11/73 microprocessor. The first of these was the calculation of the *three* sets of wind measurements (Section 3.1) along with second-order corrections to velocity measurements to better account for the physical separation of the sensors on the aircraft. The equations used in the airborne software in FIFE-89 are detailed in Reference 15.

The second major change was the use of floating point arithmetic in the airborne calculation of flux estimates, rather than the previously used single precision integer arithmetic. This has greatly improved the accuracy and resolution of the real-time flux estimates presented on the plasma display units at the end of each flux-measuring run. Other refinements used in the ground playback program have also been incorporated in the airborne program. These include high-pass filtering of the signals contributing to the fluxes, and accounting for lags due to the physical separation of the $\text{CO}_2/\text{H}_2\text{O}$ analyzer from the gust boom.

Figure 3 shows a comparison of the heat and CO_2 fluxes displayed in flight on the plasma units versus those subsequently computed on ground playback. Each symbol represents one 15-km run over the FIFE site, and all runs in Flights 04 to 06 are shown. The agreement is very good. Having these real-time estimates of fluxes during flight was of considerable assistance to the on-board scientists directing the flights. There is some scatter in Figure 3 because the real-time program still did not include all of the corrections used in the playback software. For example, the real-time CO_2 flux calculation does not include corrections for pressure broadening, nor does it use CO_2 converted to mixing ratio prior to flux calculation. Instead, the raw CO_2 concentration is used and the flux is corrected at the end of the run using the expressions developed by Webb *et al* in Reference 18. The differences in these methods are discussed further in Reference 15 and in Section 4.2.1 of Reference 1.

During FIFE-89, several versions of the airborne program were run. Table 4 lists the module used for each flight, along with the time period for which data were recorded. There were no significant differences among these modules that affected the recorded data. The differences had more to do with special tests to monitor the program in order to find the reason for occasional program halts due to a stack overflow. Also, because of a hardware failure on the event marker board, an alternate card (GNS) had to be used, which necessitated a change in the device address after July 28.

4.2 Playback

Post-flight analysis of the Twin Otter data is performed on a field data playback system comprised of a MicroVAX II processor and associated printer, plotter and tape drives. The principal analysis program, now called ARCFIFE-89, has grown considerably since 1987. It provides a greater number and variety of outputs, in order to more efficiently transfer data to other collaborating scientists. Output files stored on the MicroVAX disk can be transferred via Kermit software to PC-compatible floppy disks. The outputs available include:

- lineprinter listings of 1-second averages of key parameters, plus run-averages, standard deviations and computed fluxes.
- one-second averages of key parameters to floppy disk.
- photo summary file, with time, position, altitude and heading.
- averages over selected intervals of key parameters and the products of data contributing to the fluxes, eg., vertical gust times CO_2 fluctuations.
- summary file of run averages, unfiltered RMS values and fluxes.
- summary file of run averages, filtered RMS values and fluxes.
- filtered run averages for advection studies.
- linear trends of key parameters used in advection studies.
- archive data in the format specified for the FIFE Information System (FIS).

Several plotting routines used in the Twin Otter data playback are now grouped as options under a main driver called POKPLOTS. The plotting modules listed below accomplish the following tasks directly from the streamer tape:

- TRKDRW - Flight track plots from either Loran-C or IRS data.
- TEFDRW - Skew-T versus Log P plots and a wind hodograph for atmospheric profiling (soundings). Added in 1989 was a vector presentation of the winds.
- ANADRW - Analog plots of selected parameters.
- DPOSDT - Plots of differences in latitude and longitude between the Loran-C and IRS position measurements to document IRS Schuler drift. It also includes the difference in ground speeds measured by the IRS and Doppler radar.

Of major interest in flux measurement is a knowledge of the wavelengths of atmospheric motion contributing to the gas or energy transport. A program called COSPEC has been written to compute and plot the cospectra for the sensible and latent heat, momentum and CO_2 flux contributions versus wavenumber k (inverse wavelength). This program reads data directly from the streamer tape, producing one set of plots for each flux run, as designated by the event marker. The cospectral data are simultaneously written to a storage file. Another program called COMBINE can be used to retrieve selected cospectra

files to compute and plot *average* cospectra for a set of runs (eg., Fig. 13). These are useful, for example, for comparing the cospectra of all runs at one height with all those at a second height, in order to examine the change with height in the size of the eddies responsible for the flux transport.

4.2.1. Flux Calculations

The fluxes of sensible and latent heat, momentum and CO_2 reported below and archived in the FIS have been computed by essentially the same equations as used in 1987. These were discussed in Section 4.2.1 of Reference 1, but are much more fully described in Reference 15 and will not be reproduced here. It must be emphasized that the method used to compute the CO_2 and water vapour flux (in both 1987 and 1989) was to convert the gas concentrations to mixing ratios (per kilogram of *dry* air) prior to their use in the eddy correlation equations.

The only difference in the flux calculations for FIFE-89 from the 1987 work is that the vertical gust velocity used is that derived from the Litton winds (WEP in Table 3) as opposed to that computed from the NAE/DOP winds (WGEI). The RMS values of WEP are generally a few percent higher than those of WGEI, suggesting that the use of WEP may produce slightly higher fluxes. This has *important ramifications* if 1987 and 1989 flux data are to be compared. This subject will be discussed below in Section 7.3 on data analysis and results.

4.2.2. Longitudinal Displacement of Sensors

On the Twin Otter, there is a physical displacement between the primary sensor for the vertical gust velocity at the tip of the noseboom, and the other sensors providing data for the flux calculations. In using the eddy correlation technique to compute fluxes, the data must be adjusted for the transport time for a parcel of air to pass from the noseboom to the other sensors. This adjustment is particularly important for runs at low altitude, where the spacing of the sensors can be a greater fraction of the typical turbulent eddy size.

The Rosemount temperature probe (TSF) and dew point sensor are on the sides of the fuselage nose about 4 m aft of the noseboom tip. The $\text{CO}_2/\text{H}_2\text{O}$ analyzer is mounted in a duct through the rear of the cabin. The distance from the tip of the noseboom to the duct inlet is 9.9 m, and the analyzer is centred another 2.4 m from the duct inlet. Using the measured true airspeed of the aircraft, and the flow velocity in the duct, the theoretical time lags between the sensors can be easily calculated, as was done in Reference 1.

By means of an optional input in the playback software, the vertical gust velocity can be lagged a selectable number of sampling time periods prior to being multiplied by fluctuations in temperature, CO_2 and H_2O signals to derive the fluxes. To verify the predicted time lags, data from low-altitude runs can be analyzed with a range of lags. The resulting computed correlation coefficients are then plotted versus lag, with the maximum of the curve defining the appropriate lag for use in the subsequent data analyses. Another benefit of this technique is that the lag derived is a combination of delays resulting from both the physical separation of the sensors *and* the differences in the response times of sensors.

Figure 4 shows the plots of the correlation coefficients between the vertical gust velocity (WEP) and five other sensors. The temperature probe has a frequency response equal to that of the gust measurement, so its best lag of one time slice (1/16 sec) is due entirely to the physical displacement between the sensors. The same is true for the CO_2 and H_2O signals from the ESRI gas analyzer, but in this case the best lag to use is 5 time slices. For the dew point signal used in the calculation of an alternative water vapour flux, the peak correlation is given for a lag of 20 time slices (1.25 sec). The slow response of this sensor is responsible for the majority of the required lag. This is also the case for the LI-COR CO_2 analyzer, where a lag of 25 data points is required when used in the calculation of an alternative approximate CO_2 flux. These lags apply for flight at a true airspeed of $55\text{-}60 \text{ ms}^{-1}$, which is representative of the majority of the FIFE flux runs.

4.2.3 Corrections to Upward Radiometer

Software has been developed to continuously correct the upward radiometer reading for its mounting alignment and for variations in the pitch and roll attitude of the aircraft throughout each flight. The equations used are described in Reference 1. The procedure utilizes the following recorded data: GMT, pitch and roll attitude, heading, latitude and longitude. The only terminal input required is the sun declination angle from Table 169 of Reference 19.

4.2.4 High-pass Filtering

The analysis program, ARCFIFE89, computes the fluxes twice, using first unfiltered and then high-pass filtered data. The high-pass filtering is a convenient method to remove trends in the data at wavelengths longer than can be adequately sampled in the project runs. It is also used to permit comparison of data collected on runs of different lengths.

A third-order filter was used during the playback and archiving of the FIFE-89 data. The filter breakpoint was set to 0.012 Hz , which corresponds to a wavelength of approximately 5 km at the 60 ms^{-1} typical true airspeed of the Twin Otter.

5.0 EXPERIMENTAL SITE AND FLIGHT PATTERNS

The Konza Prairie southeast of Manhattan, Kansas was again the focus of FIFE-89. The prairie itself, roughly 6 km on a side constituted the northwest portion of the 15x15 km study area. The Konza portion of the FIFE study area is a controlled experiment site 3487 hectares in area, consisting primarily of native tallgrass prairie vegetation, and is a long term ecological research site supported by the U.S. National Science Foundation. Controlled treatments on the Konza consist of grazed and ungrazed, burned and unburned areas in various annual rotations. The non-Konza part of the FIFE site is privately held and consists mainly of grazed and burned land. In FIFE-89, flight crews observed that the southeast quadrant appeared to be greener than the others, and also looked as if it had been seeded.

More complete descriptions of the FIFE site are available in References 1 and 20. The principal difference in the 1989 surface measurements was the concentration of most of the instrumentation in three 'supersites' known at Sites 906, 916 and 926 (Fig. 5). The University of Wisconsin LIDAR was again scanning the southwest quadrant from a location near the intersections of Highways I-70 and K-177.

Figures 5 to 7 show the tracks and navigational waypoints used in FIFE-89. In the flight and data summaries given below, the track flown on each run is identified using the waypoint labels shown in these figures. Figure 5 focuses on the tracks used on L- and T-shaped flight patterns, usually flown at several altitudes up to the top of the mixed layer in order to determine a flux profile. These were often done in coordination with the NCAR King Air. Figure 6 shows the tracks used on the grid flights, which were flown only by the Twin Otter, and at a single height of 1600 ft above sea level (approximately 100 m above ground). During some of the grid flights flown by the Twin Otter, the NCAR King Air made simultaneous profile measurements or flew the double-stack pattern (Ref. 11) for estimating advective contributions to the flux estimates.

As in 1987, the flux aircraft flew a so-called 'regional run' during transit to and from the base at Salina. These runs of about 75 km in length were always flown at 500 ft (150 m) above ground. The data from these runs are used to examine long wavelength contributions to the fluxes, to investigate the possibility of scaling-up flux estimates made on the shorter runs over the FIFE site to account for potential unmeasured longwave eddies. The regional run is flown over a greater variety of vegetation, from the Konza Prairie at the eastern end to mixed farmland and bare, ploughed fields at the west end. This variety makes the data useful for comparison with remote sensing images from satellite and the NASA C-130. The regional run for 1989 was changed from that flown in 1987, in order to have a better balance between Konza-type prairie grasses and the mixed farmland. The eastern end of the run was moved to the east edge of the FIFE site (Fig. 7), so about a fifth of the run was over the FIFE site

itself, and about half the run was over similar vegetation. This improves the chances of using data from the regional run to correct FIFE-site flux estimates for long wavelength contributions. The track labelled 'B' in Figure 7 was flown only on Flight 01. All of the other regional runs were flown on track-C, which was displaced further south to avoid traffic conflicts at Fort Riley.

Other types of flight patterns were similar to those flown in 1987 and discussed in Reference 1. They included: (1) soundings over or near the FIFE site to document the thermal and dynamic structure of the atmosphere during each flight; (2) over-flight intercomparisons with the LIDAR; (3) wing-to-wing intercomparisons with the NCAR King Air, including 75 km of formation flight on the regional run; and (4) low-altitude runs over the Tuttle Creek Reservoir for verification of surface temperature measurements.

6.0 SUMMARY OF FLIGHT OPERATIONS

The Twin Otter arrived in Salina on July 21, 1989, and flight operations for FIFE-89 began on July 24. Sixteen project flights and several test flights were flown during the following three-week Intensive Field Campaign (IFC). The aircraft returned to its home base in Ottawa on August 14. Including transit and test flights, the Twin Otter was flown a total of 69.2 flying hours in FIFE-89.

Details of the Twin Otter flight operations and instrumentation status during FIFE-89 are presented in three tables, which should be *key references* for scientists working with Twin Otter data:

Table 5: FIFE-89 Flight Summary: This table lists *all* FIFE-related Twin Otter flights, including transit and test flights. It gives flight times (GMT), project flight number, and a brief description of the weather. It summarizes all of the measurement runs and the pressure altitudes flown (average terrain elevation of the FIFE site is about 1380 ft msl). Under "location", the waypoints given are those shown in Figures 5 to 7.

Table 6: Types and Numbers of Runs: This table lists the flights by type (project, transit and test) and gives the number of runs flown in the categories described in Section 5. These are grid lines, L- and T-shaped profiling runs, other linear runs, regional runs, aircraft-to-aircraft and aircraft-to-LIDAR intercomparisons, and soundings.

Table 7: Instrumentation Problems: This presents the instrumentation status for each of the 16 FIFE-89 project flights. In listing individual problems, parameter names correspond to those appearing in Tables 1 and 3.

Flight tracks for the 16 project flights are presented in Figures 8(a) to 8(d). Figures 9(a) to 9(c) show profiles of the measured wind, temperature and dew point for the soundings flown over or near the FIFE site. Winds are shown in both a hodograph and vector presentation. No soundings were flown on Flights 02, 05, 07 and 09.

7.0 DATA ANALYSIS AND RESULTS

Twin Otter data were analyzed using the procedures described above in Section 4.2 and the equations given in Reference 15. Copies of some of the various output files have been transferred to collaborating scientists at Agriculture Canada, the University of Wyoming and McGill University for further, specific analyses. Archive data has been sent via floppy disk to the FIFE Information System at the NASA Goddard Space Flight Center. The files consist of run-average meteorological and flux data, along with other parameters giving aircraft position and altitude and radiation measurements.

Table 8 lists the parameters archived for the flux aircraft, along with the units used and the digital formats. For each flight there is one data file named by the following convention: a two letter code for the aircraft (where the Twin Otter is NA), a 6-number date and a single letter extension indicating mission number of the day. An example for the Twin Otter for the second flight on August 4 is "NA890804.B".

Within each file there are eight lines of data for each flux run. The first line provides flight and run identification. Table 8 lists the data written in the other seven lines. It should be noted that for the FIS archive of the aircraft data, it was decided to use fluxes derived from high-pass filtered data. The wavelength for the filter was agreed to be 5 km, as previously described. Also, the sign convention adopted for the wind components was different from that usually used in the Twin Otter analysis routine. The north/south component (V) is considered positive from the south (-UGE), and the east/west component (U) is positive from the west (-VGE). This convention applies to the momentum fluxes as well. The more conventional momentum flux in wind axes is also archived. Because of this difference in the sign convention for the winds, care must be taken if the data from Table 9 of this report are compared with the archive data in the FIS.

7.1 Summary of Results

Table 9 presents run-average data from all of the runs flown by the Twin Otter in FIFE 1989. This is an important addition to this report that was not included in the parallel report (Ref. 1) for the 1987 FIFE project.

The RMS and flux data in Table 9 were computed from data that were high-pass filtered with a breakpoint set to 0.012 Hz, which corresponds to a wavelength of about 5 km at the speed of the Twin Otter. These data correspond to those archived in the FIFE Information System. The starting time of each run is shown as GMT (Central Daylight Time plus 5 hours). An explanation of the data appearing in each column is given at the start of the table.

Data from this table were extracted and plotted to try to determine any major trends in the fluxes and evidence of 'dry-down'. Only the runs flown at 1600 ft above sea level (about 100 m above ground) were used for this study. This includes *all* runs flown on the grid pattern, plus the lowest levels flown on the L- and T-shaped flight patterns. The results are plotted in Figure 10 versus the day of the year (Day 208 is July 27). Each symbol represents the average of 4 to 10 runs; the average from each 8-line grid is shown by the asterisk symbol. Although the data shown are for mostly sunny conditions, no attempt was made to distinguish between different wind conditions or atmospheric stabilities.

The ratio of sensible heat to latent heat flux (Bowen Ratio) depicted in the upper figure shows a decline until Day 216 (August 4), then an increase to near the end of the experimental period. This suggests a drying out of the Konza Prairie over the last half of the Intensive Field Campaign (IFC). These data will have to be compared with surface and satellite observations to confirm this. The mean CO_2 flux measured by the Twin Otter was relatively constant over the experimental period, averaging about 0.5 mg/m^2 per second ($18 \text{ kg/hectare per hour}$). This falls about mid-way between the July 11 and August 15 data from the 1987 FIFE flights (Fig. 65, Ref. 1). The solid curve shown in Figure 10, representing a smooth fit through all the data points, shows a peak on day 219 (August 7). On this day, a T-shaped pattern was flown (Fig. 8(c)) in conditions of northeast winds. CO_2 fluxes were higher than average because the aircraft spent a greater proportion of its time downwind of the greener vegetation in the southeast quadrant of the FIFE area. The dotted line in Figure 10 shows trend data from only the grid runs, confirming a fairly constant CO_2 flux over the IFC.

7.2 Night Flight

One of the unique features of the Twin Otter operations in FIFE-89 was the measurement of fluxes after dark on August 10 (Flight 14). The flight commenced near sundown in order to establish a safe flight pattern and altitude prior to the onset of darkness. Starting at 20:18 local time, a racetrack pattern was established with east/west runs over Site 916 and just south of Site 906 (Fig. 8(d)). The first pair of runs was flown at 1800 ft msl, and all subsequent runs were flown at the 1600 ft altitude (100 m above ground) common to the grid flights. Throughout the flight, the height of the mixed layer was monitored by

an acoustic sounder at Site 906 and radioed to the flight crew.

Although the winds were perfect for the flight (south at 8 ms^{-1}), the sky cleared at sunset, causing the top of the mixed layer to fall more rapidly than desired. The sounder measured the height of the mixed layer at 150 m during the first run, falling to 90 m by the time of Run 10 and then rising to 120 m by the time of the last run at 02:37 GMT (21:37 local time). Therefore, the aircraft was near the top of the boundary layer for nearly all of the runs. Consequently, it was extremely smooth and measured fluxes were very low (Table 9(n)). Nevertheless, positive, or upward, CO_2 fluxes were measured, but the mean values were small (approximately $0.2 \text{ kg/hectare per hour}$). Unfortunately, there wasn't an opportunity to repeat this flight in the cloudy, windy conditions more suitable for estimating the respiration component of the CO_2 flux. However, the operational techniques developed for this flight proved that low-altitude flux measurements could be accomplished safely at night at flight altitudes with terrain clearance down to about 50 m.

7.3 The Effects of the Use of the Litton Winds in Fluxes

As discussed in Section 4.2.1 above, the only significant difference in the flux calculations for FIFE-89 was the use of the vertical gust velocity WEP from the Litton winds, rather than WGEI from the NAE/DOP winds as in 1987. To investigate the effects of this change, about 60 runs from flights on August 4 and August 10 were analyzed using both methods. Forty-five of these runs were flown on the grid pattern at an altitude of about 100 m agl. The remainder were flown at higher altitudes, usually near the top of the mixed layer, which broadens the range of flux values in this study. The results from a comparison of these data will be presented in this section.

Figure 11 shows plots of the run-mean fluxes using WEP versus those computed using WGEI. The dashed line represents the 1:1 correlation. The sensible heat, latent heat and CO_2 fluxes show a fairly consistent increase when WEP from the Litton winds is used as the vertical gust velocity. The increases are of the order of 10 to 20 percent. The momentum flux is an exception, primarily because different horizontal wind components are used in each case, that is, the Litton U-component is used with WEP and the NAE/DOP U-component is used with WGEI. Momentum flux is also a more difficult and variable flux to measure by aircraft. Although there is more scatter, it would appear that there is no consistent bias in the momentum flux that can be attributed to use of the Litton or NAE/DOP winds.

A closer look at the flux calculations has revealed that the larger fluxes are not just a result of the increased RMS vertical gust velocity when using WEP; there is also an improved correlation between the vertical gust and the concentration measurements, particularly for the water vapour. Figure 12 shows that the RMS WEP is consistently larger than that of WGEI, by an average of

about 7 or 8 percent. The correlation coefficients from the CO_2 flux calculation show an average 3 or 4 percent improvement when WEP is used. This improved correlation is evidence that the vertical component WEP from the Litton winds is likely more accurate than the WGEI from the Doppler winds.

There is further evidence for this conclusion. In 1987, the Twin Otter flew wing-to-wing intercomparisons with both the NCAR and University of Wyoming King Air aircraft. The data showed excellent agreement in the RMS values of the horizontal components of the computed winds (σ_u and σ_v in Fig. 59 and Section 8.3, Reference 1). However, there was a discrepancy in the vertical component, σ_w , where the Twin Otter values were 10-15 percent less than those of the other aircraft. In 1987, the Twin Otter σ_w was computed from the WGEI of the NAE/DOP winds. Inertial navigation systems were used in the calculations of the King Air winds, a method which is comparable to the 1989 WEP calculations for the Twin Otter. Twin Otter heat fluxes were also a few percent lower than those from the King Air aircraft (Fig. 61, Reference 1). In fact, the differences are very similar to those exhibited in Figure 11 of this report.

Since there are small but significant disparities in the computed fluxes associated with the use of either WEP or WGEI, the question arises as to the nature of these differences on the frequency plane. Do they occur at a preferred wavelength, or are the differences prevalent at the long or the short wavelengths? To investigate this, cospectra have been calculated for all sixteen runs flown in the grid pattern on Flight 06 on August 4, 1990, first using WEP and then using WGEI as the vertical gust velocity. The COMBINE routine was used to average and plot the mean cospectra from the WEP (solid line) and WGEI data (dashed line) in Figure 13. In order to observe possible differences over the largest possible wavelength range (i.e., up to the run length of 15 km), the data contributing to the fluxes had linear trends removed, but were *not* high-pass filtered.

Several observations can be made from these plots. First, the differences occur at the mid and low frequency end of the plot, that is, there is little difference in the cospectra at $k > 4 \times 10^{-3} \text{ m}^{-1}$ (wavelengths shorter than 250 m). This is not surprising, since the main difference in the methods is the use of the Doppler radar to provide the low frequency component of the inertial velocity used in the WGEI calculation. Also, at the higher frequencies, the response of the aircraft is damped by its own inertia, so the majority of the fluctuations in the gust measurement are from the noseboom airspeed and flow angle data, which are essentially the same in the calculation of both WEP and WGEI.

The differences shown in the integrated cospectra, i.e., the average fluxes shown in the legend above each plot, are consistent with the observations from Figure 11. The ratios of WEP/WGEI-derived fluxes is 1.23 for the sensible heat flux, 1.16 for latent heat flux and 1.09 for the CO_2 flux. The mean

momentum flux is the same for both the NAE/DOP and Litton winds. Since the momentum flux involves *only* wind measurements, the agreement between the NAE/DOP and Litton estimates demonstrates an internal consistency and suggests that there are no problems due to axis misalignment or in the axis transformation software.

It can be concluded from this study that, if there are differences in fluxes computed from WGEI and WEP, the latter are probably the more accurate and will certainly be the more comparable with the other aircraft. It also suggests that some caution will have to be exercised when comparing Twin Otter fluxes from 1987 with those of FIFE-89. *It is possible that the 1987 sensible heat, latent heat and CO₂ fluxes are under-estimated by 10 to 20 percent.* This may also explain part of the under-estimation of the 1987 aircraft-measured sensible heat fluxes when extrapolated to the surface for comparison with data from ground-based systems (Reference 11).

7.4 Effects of Filtering and Run Length

For the Twin Otter data archived in the Fife Information System, the fluxes were computed using data that were high-pass filtered at 0.012 Hz, which corresponds to a wavelength of about 5 km at the typical flight speed. This wavelength represents about 1/3 of the run length over the FIFE site. The question arises as to how much the fluxes are under-estimated due to: (1) use of the high-pass filter, and (2) the inability to capture the long wavelength eddies due to the limited length of the runs themselves.

The first of these questions is the easier to answer. Figure 14 shows average cospectra for the 16 runs on the grid pattern during Flight 06. The fluxes were calculated using the vertical gust velocity WEP from the Litton winds, and linear trends were removed from the data prior to application of the eddy correlation technique to derive the fluxes. Cospectra using unfiltered data are represented by the solid line, while the dotted line shows those from the same runs using high-pass filtered data. The differences are small, with the unfiltered mean fluxes only 5-10 percent more than those derived from the filtered data. The average altitude for these runs was about 100 m. Of course, the effect of the filtering will increase with height where the eddy sizes are larger.

There has been some concern during the FIFE analysis period about the apparent underestimation of the sensible heat flux by all of the flux aircraft. Therefore, it was decided to look more closely at the effects of the high-pass filtering on the estimates of the heat flux from the Twin Otter. In Figure 15, the heat flux computed from unfiltered data is plotted versus that using data high-pass filtered at a wavelength of 5 km. Each dot represents one 15-km run over the FIFE site, while the crosses depict fluxes on a 37-km segment (i.e., half) of the regional run. All runs flown in 1989 below 300 m altitude above ground are

shown, except for the night flight and a few cases in the last half of Flight 7 in which there was a large east/west trend in the potential temperature. The data contributing to both the filtered and unfiltered fluxes were not detrended prior to flux calculation.

Although there is a lot of scatter in the plots, the unfiltered flux is larger than the filtered estimate in the majority of the 15-km runs, and in *all* of the longer, more reliable regional runs. In the shorter runs over the FIFE site, the unfiltered flux is occasionally less than the filtered value. This is because negatively correlated, long wavelength components of the temperature and vertical wind signals can result in a negative contribution to the run-average flux. It is not always known whether these longwave components are real or false as a result of instrument drift. That is why the 5-km filter was adopted for the aircraft data in the first place. Nevertheless, Figure 15 suggests that a significant portion of the 'missing heat flux' is due to use of the high-pass filter and inadequate sampling of the long wavelength contributions to the flux.

The dashed line represents a linear fit to the data from the 15-km runs over the FIFE site, while the solid line depicts a 1:1 relationship. On average, the unfiltered fluxes are 15-20 percent greater than the filtered values. These differences are larger than those indicated in Figure 14 because this analysis includes runs at higher altitudes, where eddies are larger and proportionally more affected by the 5-km high-pass filter. The 15-20 percent difference represents about half of the discrepancy reported between the 1987 aircraft versus surface fluxes. Use of the Doppler rather than the Litton winds in 1987 (Section 7.3) could account for at least another 10 percent heat flux decrease, or a quarter of the discrepancy. Furthermore, it has also come to light at a recent workshop that overestimated net radiation measurements have led to a possible overestimation in the surface-measured heat flux values.

There is another interesting observation to be made from Figure 15. The dotted line depicts the linear fit to the data for the 37-km segments (i.e., half) of the regional run. It does not have as steep a slope as the dashed line for the 15-km runs, that is, the unfiltered/filtered ratio is greater on days with small fluxes than on large flux days. This suggests that, on low flux days, proportionally more of the flux contribution on the regional run is at long wavelengths. This effect is not seen for the 15-km runs, where the reduction by the filter appears to be about the same *percentage* on large and small flux days. This comparison implies that the difference is due to flux contributions at wavelengths longer than 15 km, which can be sampled on the regional run but not on the 15-km runs, and that these very long wavelength contributions are more prevalent on low flux days than on high flux days. Admittedly, these inferences are drawn from linear fits to data that have a lot of scatter, but they are consistent with the observation that aircraft-measured fluxes are lower than surface estimates. The subject deserves further investigation, possibly by comparing filtered and unfiltered fluxes from the entire 75-km regional run with averages from the same runs divided into 15-km segments.

Further to the question about underestimation caused by the limited run length, the unfiltered cospectra in Figure 14 show good closure at the long wavelength end, suggesting that there is little energy at wavelengths longer than 15 km. The flight altitude was only 100 m, however, and the data shown are from only one day; the results could conceivably change on another day with a different wind direction or atmospheric stability. This is discussed further in Reference 4, where filtered and unfiltered cospectra were calculated for some 75-km regional runs flown in 1987. A comparison of data from two days showed significant differences in the long wavelength contributions to the fluxes. It is hoped that such data from the regional runs can be used to normalize, or scale up, fluxes from the shorter runs over the FIFE site in order to account for the potentially missing long wavelength contributions.

8.0 CONCLUDING REMARKS

This report has documented the participation of the NAE Twin Otter atmospheric research aircraft in FIFE-89. It has provided the details of the instrumentation on the aircraft, real-time and playback software, and flight operations during the experiment. The various forms of data available to collaborating scientists have been listed, including the format of the data residing in the FIFE archive at the NASA Goddard Space Flight Center.

Also presented in this report were run-average meteorological, radiation and flux data for all 285 runs flown by the Twin Otter in FIFE-89.

FIFE-89 was the first flux-measuring project in which the alternative wind calculations have been available on the Twin Otter. The difference in the wind computation methods was primarily in the source of the aircraft inertial velocity measurement. Winds referred to as the NAE/DOP winds were used for the 1987 FIFE data, while those called the Litton winds have been used for archiving FIFE-89 data. Data for runs analyzed by both methods show flux increases of 10 to 20 percent when the Litton winds provide the vertical gust velocity used in the flux calculations. It is possible, therefore, that fluxes archived for FIFE in 1987 were under-estimated by that amount.

Analysis of FIFE-87 data has indicated that aircraft-measured sensible heat fluxes, when extrapolated to the surface, under-estimate surface-based flux measurements. Studies in this report suggest that at least half of this discrepancy is a result of the combined effects of a limited run length of 15 km, and the high-pass filtering of the aircraft data at a wavelength of 5 km.

FIFE-89 included the first attempt to make low-altitude flux measurements at night. Although the meteorological conditions were not ideal for this purpose, the operational techniques developed for this flight proved that low-altitude flux measurements could be accomplished safely at night at flight altitudes down to about 50 m.

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10.0 REFERENCES

1. MacPherson, J.I. NAE Twin Otter Operations in FIFE.
NRC, NAE Laboratory Technical Report
LTR-FR-104, August, 1988.
2. Schuepp, P.H. Interpretation of Airborne Estimates of
Desjardins, R.L. Evapotranspiration.
MacPherson, J.I. International Association of Hydrological
Boisvert, J.B. Sciences, Pub # 177,(Proceedings of IUGG
Austin, L.B. Workshop on Evapotranspiration), pp. 185-
196, Vancouver, August 1987.
3. Desjardins, R.L. Divergence of CO₂, Latent and Sensible
MacPherson, J.I. Heat Fluxes: A Case Study.
Betts, A.K. Proceedings of the Symposium on Lower
Schuepp, P.H. Tropospheric Profiling: Needs and
Grossman, R. Technologies, Boulder, Colorado,
May 31-June 3, 1988.

4. Desjardins, R. L.
MacPherson, J. I.
Schuepp, P. H. Long Wavelength Contributions to Aircraft-based Flux Estimates of CO_2 , H_2O and Sensible Heat.
Proceedings of the 19th Conference on Agricultural and Forest Meteorology, Charleston, S.C., March, 1989.
5. Duncan, M.
Schuepp, P. H.
MacPherson, J. I.
Desjardins, R. L. Statistical Analysis of Airborne Flux Measurements Over the FIFE Site.
Proceedings of the 19th Conference on Agricultural and Forest Meteorology, Charleston, S.C., March, 1989.
6. Betts, A. K.
Desjardins, R. L.
MacPherson, J. I.
Kelly, R. D. Boundary Layer Heat and Moisture Budgets.
Paper presented at the Spring 1989 Meeting of the American Geophysical Union, Baltimore, MD, May, 1989.
7. Schuepp, P. H.
Leclerc, M. Y.
Desjardins, R. L.
MacPherson, J. I. Footprint Prediction of Scalar Fluxes: Reliability and Implications for Airborne Flux Measurements over the FIFE Site.
Proceedings of the AMS Symposium on the First ISLSCP Field Experiment (FIFE), Anaheim, California, Feb. 7-9, 1990.
8. Betts, A. K.
Desjardins, R. L.
MacPherson, J. I.
Kelly, R. D. Boundary Layer Heat and Moisture Budgets from FIFE.
Proceedings of the AMS Symposium on the First ISLSCP Field Experiment (FIFE), Anaheim, California, Feb. 7-9, 1990.
9. Desjardins, R. L.
MacPherson, J. I.
Schuepp, P. H. Spatial and Temporal Variations of CO_2 , Sensible and Latent Heat Fluxes over the FIFE Site.
Proceedings of the AMS Symposium on the First ISLSCP Field Experiment (FIFE), Anaheim, California, Feb. 7-9, 1990.
10. Kelly, R. D.
MacPherson, J. I.
Grossman, R. L.
Eloranta, E. W.
Brutsaert, W.
Gal-Chen, T. Design and Operation: Atmospheric Boundary layer Studies.
Proceedings of the AMS Symposium on the First ISLSCP Field Experiment (FIFE), Anaheim, California, Feb. 7-9, 1990.

11. Betts, A. K.
Desjardins, R. L.
MacPherson, J. I.
Kelly, R. D. Boundary Layer Heat and Moisture Budgets from FIFE.
Boundary Layer Meteorology, 50: 109-137, 1990.
12. Schuepp, P. H.
Leclerc, M. Y.
MacPherson, J. I.
Desjardins, R. L. Footprint Prediction of Scalar Fluxes from Analytical Solutions of the Diffusion Equation.
Boundary Layer Meteorology, 50: 355-371, 1990.
13. MacPherson, J.I.
Morgan, J.M.
Lum, K. The NAE Twin Otter Atmospheric Research Aircraft.
NRC, NAE Laboratory Technical Report LTR-FR-80, March 1981.
14. MacPherson, J.I.
Baillie, S. The NAE Atmospheric Research Aircraft. Presented at the AGARD Structures and Materials Panel Workshop, Athens, September 1986.
Published in AGARD Report No. 734, The Flight of Flexible Aircraft in Turbulence.
15. MacPherson, J. I. Wind and Flux Calculations on the NAE Twin Otter.
NRC, NAE Laboratory Technical Report, LTR-FR-109, February, 1990.
16. Britting, K. R. Inertial Navigation Systems Analysis.
Wiley-Interscience, 1971, 249 pp.
17. Leach, B. W.
MacPherson, J. I. An Improved Airborne Wind Measurement Technique for the NAE Twin Otter.
NRC Aeronautical Note NAE-AN-61, November, 1989.
18. Webb, E. K.
Pearman, G. I.
Leuning, R. Correction of Flux Measurements in Density Effects Due to Heat and Water Vapour Transfer.
Quarterly Journal of the Royal Meteorological Society, 106, 1980, 85-100.

19. List, R. J. Smithsonian Meteorological Tables, 114,
Smithsonian Institution, Washington, 1951.

20. Sellers, P. J. FIFE-89 Experiment Plan.
Hall, F. G. Goddard Space Flight Center, July, 1989.

TABLE 1: TWIN OTTER SENSORS FOR FIFE-89

Category	Instrument	Type ¹ Output	Parameter Labels	Description
Time	NAE Clock	D	HR, MINSEC	
Position	ARNAV Loran-C, R-40-AVA-100	D	LTD, LTM	Latitude, degrees and minutes
			LGD, LGM	Longitude, degrees and minutes
	Litton LTN-90-100	D	LTML	Latitude, minutes
	Inertial Reference System		LGML	Longitude, minutes
Inertial Velocity	Litton LTN-90-100	D	ULN,VLE,WZL	3 Components of Velocity in Earth-axes
	Inertial Reference System		GSL	Total Ground Speed
Heading	Decca Doppler Radar, Model 72	D	VXM,VYM,VZM	3 Components of Velocity in Aircraft Axes
			VDTM	Total Ground Speed
	Sperry C-12 Gyro Compass	S	HDGM	Magnetic Heading
			HDGT	True Heading (Uses Variation from Loran)
Attitudes	Litton LTN-90-100 IRS	D	HDGTL	True Heading
	Kearfott T2109 Gyro	S	THETA, PHI	Pitch and Roll Attitude
	Litton LTN-90-100 IRS	D	THETAL, PHIL	Pitch and Roll Attitude
Accelerations	Systron-Donner 4211	A	AX,AY,AZ	Longitudinal, Lateral and Vertical Accelerations in Aircraft Axes
	Litton LTN-90-100 IRS	D	AXL,AYL,AZL	As above
Angular Rates	Smiths 402-RGA Rate Gyros	A	PRATE,QRATE	Roll, Pitch and Yaw Rates
			RRATE	in Aircraft Axes
Altitude	Litton LTN-90-100 IRS	D	PRATEL,QRATEL	As above
			RRATEL	
Altitude	Sperry AA-200 Radio Altimeter	A	RALT	Height Above Terrain, to 2500 ft
Temperatures	Rosemount 102DJ1CG	A	TTF	Fast Response Total Temp at Fuselage Nose
	Rosemount 102DJ1CG	A	TTNB	Fast Response Total Temp on Noseboom Fairing
	Rosemount 102DJ1CG	A	TTDUCT	Fast Response Total Temp in Duct
	Barnes PRT-5	A	PRT5C	Surface Temperature
	E,G and G Model 137-S10	A	DEWPTC	Dew Point Temperature

¹ D- Digital S- Synchro A- Analog

TABLE 1 (Cont): TWIN OTTER SENSORS FOR FIFE-89

Category	Instrument	Type ² Output	Parameter Labels	Description
Temperatures (Cont)	Paroscientific 215L-AW-012	A	TSPARO	Temperature in Static Pressure Transducer
	Ag Canada	A	TSANAL	Temperature in CO ₂ /H ₂ O Analyzer
	LICOR CO2 Analyzer temp	A	LCTSC	Temperature in LICOR CO2 Analyzer
Pressures	Paroscientific 215L-AW-012 Rosemount 858AJ28 Probe	D	PSNB	Noseboom Static Pressure, temperature compensated
	Rosemount 12211V7A18 Rosemount 858AJ28 Probe	A	PDNB	Noseboom Dynamic Pressure
	Rosemount 12211F1VL5A1 Rosemount 858AJ28 Probe	A	PALPHA	Differential Pressure for Angle of Attack
	Rosemount 12211F1VL5A1 Rosemount 858AJ28 Probe	A	PBETA	Differential Pressure for Angle of Sideslip
	Rosemount 1201F1B4A1B	A	PSF	Alternate Static Pressure, Fuselage
	Rosemount 1201F2VL7A1A	A	PDF	Alternate Dynamic Pressure, Fuselage
	Rosemount 1221F2VL7A1A	A	PDDUCT	Dynamic Pressure in Duct
	A.I.R. AIR-DB-2C	A	PSDUCT	Static Pressure in Duct
Analyzers	Agriculture Canada ESRI Gas Analyzer	D	CO2NO2 H2O	Carbon Dioxide Concentration Water Vapour Concentration
	LICOR LI-6251 CO2 Analyzer	A	LCO2	Carbon Dioxide Concentration
Radiometers	Kipp and Zonen CM-11	A	RADUP	Incident Radiation, Top Fuselage
	Eppley Pyranometer	A	RADOWN	Reflected Radiation, Under Fuselage
	Skye Industries Greenness	A	GRN660 GRNRAT	Vegetation Greenness Index

² D- Digital S- Synchro A- Analog

TABLE 2

Event Marker Configuration for FIFE 1989

Bit	Decimal Count	Label on Printout	Indication
15	negative	-	No event
14	16384	E	Event Marker ON: Data run
13	8192	P	35 mm photograph taken (tied to camera sync pulse)
12	4096	N	Notepad cassette recorder being used for audio note taking
11	2048	C	LICOR CO ₂ analyzer in self-calibration
10	1024	T	VHF radio transmission
9	512	M	Doppler radar in memory; velocities not useable
8	256	L	Loran-C data not available
7	128	-	F/S 7 ¹ - Navigation pointer routine running; used to return to same air parcel or cloud
6	64	S	F/S 6 - Doppler radar land or sea calibrations to be used
5	32	5	F/S 5 - OFF - TSNB used in TAS - ON - TSF used in TAS, etc
4	16	4	F/S 4 - Position error adjustment subtracted from noseboom TAS
3	8	I	F/S 3 - Noseboom dynamic pressure port blocked; Alternative PDFNB used in flow angle calculation
2	4	F	F/S 2 - Fuselage true airspeed used in wind calculation instead of noseboom TAS
1	2	-	F/S 1 - Wind data displayed to crew in degrees magnetic or true
0	1	-	F/S 0 - Not used

¹ F/S indicates function switch on console in cockpit. Status of the 8 function switches are recorded in the event word

TABLE 3

TWIN OTTER RECORDER BUFFER IN FIFE-89

BUFFER A FIFE89 for use with Litton Running
Used for all FIFE-89 Flights

Word #	Name	Scale	Units	Description
01	FILEHR	1	-	File number; GMT hours (1)
02	MINSEC	1	-	GMT minutes; GMT seconds (2)
03	EVENT	1	-	Event marker
04	LTD	1	deg	Loran latitude, degrees
05	LTM	100	min	Loran latitude, minutes
06	LGD	1	deg	Loran longitude, degrees
07	LGM	100	min	Loran longitude, minutes
08	LTML	100	min	Litton latitude, minutes
09	LGML	100	min	Litton longitude, minutes
10	HDGT	10	deg	Magnetic compass true heading
11	HDGTLC	10	deg	Litton true heading
12	WDTI	10	deg	Dop/inertial true wind direction
13	WDTL	10	deg	Litton true wind direction
14	WSMI	100	m/s	Doppler/inertial wind speed
15	WSML	100	m/s	Litton wind speed
16	UGEI	100	m/s	North/south Dop/In wind component (positive from north)
17	VGEI	100	m/s	East/west Dop/In wind component (positive from east)
18	WGEI	100	m/s	Vertical Dop/In wind component (positive up)
19	LWN	100	m/s	North/south Litton wind component
20	LWE	100	m/s	East/west Litton wind component
21	WEP	100	m/s	Vertical Litton wind component
22	TSNBC	100	deg C	Static temperature, noseboom fair'g
23	DEWPTC	100	deg C	Dew point temperature
24	TSDCTC	100	deg C	Duct static temperature, fast response R-102 probe
25	PRT5C	100	deg C	PRT-5 surface temperature
26	RADUP	10	W/m ²	Incident radiation, upward facing
27	RADOWN	10	W/m ²	Reflected radiation, downward "
28	CO2N02	10	mg/m ³	CO ₂ analyzer, duct, LP filtered
29	H2O	100	g/m ³	H ₂ O analyzer, duct, LP filtered
30	RALT	10	m	Radio altimeter height
31	TASFK	100	knots	True airspeed, fuselage
32	TASNBK	100	knots	True airspeed, noseboom
33	TASDCT	100	knots	True airspeed, duct
34	PSDUCT	10	mb	Static pressure, duct
35	PSNBC	10	mb	Static pressure, noseboom
36	TSFC	100	deg C	Static Temperature, fuselage
37	GRNRAT	1000	-	Greenness index
38	VDTM	10	m/s	Doppler ground speed
39	GSL	10	knots	Litton ground speed
40	LC02	1	mv	Licor CO ₂ analyzer, millivolts

TABLE 3 (Cont)

Word #	Name	Scale	Units	Description
41	LCTSC	100	deg C	Licor CO ₂ analyzer temperature
42	UGEIL	100	mps	North/South Litton/Dop wind
43	VGEIL	100	mps	East/West Litton/Dop wind
44	WGEIL	100	mps	Vertical Litton/Dop wind
45	UCO ₂ N ₂	10	mg/m ³	CO ₂ Analyzer, duct, unfiltered
46	UH ₂ O	100	g/m ³	H ₂ O Analyzer, duct, unfiltered
47	TTF	100	deg K	Rosem't total temperature, fuselage
48	TTNB	100	deg K	Rosem't total temperature, noseboom
49	PSFC	10	mb	Fuselage static pressure
50	PDFC	100	mb	Fuselage dynamic pressure
51	PDNBC	100	mb	Noseboom dynamic pressure
52	AZL	100	m/s ²	Vertical Acceleration, Litton,
53	PDDUCT	100	mb	Duct dynamic pressure
54	WGAI	100	m/s	Vertical Dop/Inertial wind component in aircraft axes
55	ALPHA	100	deg	Angle of attack, noseboom
56	BETA	100	deg	Sideslip angle, noseboom
57	THETAL	100	deg	Pitch attitude, positive nose up
58	PHIL	100	deg	Roll attitude, positive right wing down
59	VXMLTN	128	m/s	Doppler velocity along heading corrected to Litton location
60	VYMLTN	256	m/s	Doppler lateral velocity, positive to starboard
61	VZMLTN	512	m/s	Doppler vertical velocity, positive aircraft down
62	ULN	100	m/s	Litton north/south velocity, positive to north
63	VLE	100	m/s	Litton east/west velocity, positive to east
64	WZL	100	m/s	Litton vertical velocity,

Notes: (1) first byte is tape file number, decimal
second byte is GMT hours, decimal

(2) eg., 2712 decimal is 27 minutes, 12 seconds GMT

TABLE 4: AIRBORNE PROGRAMS AND RECORDED DATA

Date	Flt #	Program	Version	File	Recorded GMT ¹
Jul 27	01	PK9CF1	Jul 26	1	1521-1525
		"	"	2	1532-1819
"	02	PK9CH1	Jul 26	1	1909-1950
Jul 28	03	PK9CF1	Jul 26	1	1440-1804
Aug 02	04	POK9CI	Jul 29	1	1451-1825
Aug 03	05	"	"	1	1714-1945
Aug 04	06	"	"	1	1416-1724
"	07	"	"	1	1831-2126
Aug 06	08	"	"	1	1459-1830
"	09	"	"	1	1928-2236
Aug 07	10	"	"	1	1511-1529
		"	"	2	1548-1838
Aug 08	11	POK9CJ	Aug 08	1	1511-1830
"	12	"	"	1	1940-2209
Aug 10	13	POK9CL	Aug 08	1	1557-1836
"	14	"	"	1	0051-0309 ² NF ³
Aug 11	15	"	"	1	1619-2007
Aug 12	16	"	"	1	1555-1958

¹ Greenwich Mean Time = Central Daylight Time plus 5 hours

² Evening flight August 10 (August 11 GMT)

³ No end-of-file marker on tape

TABLE 5: FIFE-89 FLIGHT SUMMARY - NAE TWIN OTTER

DATE	FLT #	GMT	HRS	WEATHER	RUNS FLOWN	LOCATION Waypoints
Jul 20	-	1406-1537	1.7	Sunny	- Transit	Ottawa-Wiarton
		1716-1916	2.1	Some cloud	- Transit	Warton-Milwaukee
		2052-2221	1.7	Some cloud	- Transit	Milwaukee-Ottumwa
Jul 21	-	1455-1626	1.6	Cloud, showers to sunny	- Transit	Ottumwa-Manhattan
	00	1719-1816	1.1	Mostly sunny, some cumulus; Winds NE at 10 mps	- Test run at 1900' msl - Test run at 1900' msl - Attempt new regional run, terminated about 10 miles east of west end	FNW-FNE FN-FS FE2-FWEST
Jul 24	-	2057-2128	0.6	Towering cumulus, southeast winds	- Tests of event marker with various jumper combinations - Licor tests at high and low speed, and during taxi	
Jul 25	-	1910-1950	0.6	Cumulus	- Test of PK9CFX for event marker - Several problems after 15 volt short	
Jul 26	-	2018-2044	0.6	Cumulus, SSE winds	- 3 files using modules PK9CF1, PK9CE1 and PK9CH1 - Did pitches and several low level runs to test event and flux routines	
Jul 27	01	1522-1819	3.0	Cumulus, Winds SSW 5-7 mps, Cloud Base: 4300' @ 1600Z, 4500' @ 1638Z, 5500' @ 1736Z, 5900' @ 1809Z, altimeter 30.20	- Regional run B, 500' agl - Sounding to 4800' msl - Profile stack at 1600, 1900, 2600 and 4000' msl - Profile stack at 4300, 2600, 1900, 1600, 1700, 1900, 2600 and 4300' msl - Profile stack at 5200, 2700, 1900 and 1600' msl - Sounding to 5900' msl	- FRW-FE2, Region B - - FNW3-FNE3 - FN2-FS2 - FNW3-FNE3
Jul 27	02	1910-1951	0.8	Cumulus, Winds south 5-7 mps	- Regional Run C at 500' agl	- FE2-FRW2, Region C
Jul 28	03	1440-1804	3.5	Mostly clear, a few cumulus near end of flight, Winds south 5 mps, BL height 3700' msl at start, Altimeter 30.10	- Control inputs, 9500' - Descent sounding from 9500' - 3 Lidar intercomparison runs, 1750, 2800 and 4000' msl - 8-line grid working from south to north, 1600' msl - 8-line grid working north to south, 1600' msl - Regional run C, 500' agl	- 235 mag bearing over LIDAR site - 8 east/west lines - 8 east/west lines - FRE-FRW2
Jul 31	-	2030-2054	0.5	Partially cloudy	- 4 test runs for new POK9CI	- Near Salina

TABLE 5 (cont): FIFE-89 FLIGHT SUMMARY - NAE TWIN OTTER

DATE	FLT #	GMT	HRS	WEATHER	RUNS FLOWN	LOCATION Waypoints
Aug 02	04	1452-1825	3.7	Hazy and humid, approx 50% low cumulus, South winds 5-10 mps, Cloud base 2800' at start, rising to 3800' msl at end, Altimeter 30.00	<ul style="list-style-type: none"> - Sounding from 9500' - L-pattern, 1700 to 1600' msl - L-pattern 2600' msl, 200' below cloud base - L-pattern, 1600' msl - L-pattern, 2600' msl - L-pattern, 2800' msl - L-pattern, 1600' msl - L-pattern, 3000' msl - L-pattern, 1600' msl - One Lidar Intercomp, 205 magnetic, 3400' msl - Regional run C, 500' agl 	<ul style="list-style-type: none"> - FS3-FN3, FNW-FNE - FNE-FNW, FN3-FS3 - FS3-FN3, FNW-FNE - FNE-FNW, FN3-FS3 - FS3-FN3, FNW-FNE - FNE-FNW, FN3-FS3 - FNE-FNW, FN3-FS3 - 205 bearing from over Lidar - FRE-FRW2
Aug 03	05	1715-1946	2.7	Low cloud at start, 30 -40 % based at 2800' msl; reduced to about 20% and cloud base rose to 4100', Winds 220/10 mps, Altimeter 29.79	<ul style="list-style-type: none"> - Regional run C, 500 agl - 3 familiarization runs for new pilot, 1600' msl - 4 Lidar intercomparison runs (first aborted about mid way) 2800, 2800, 1600 and 3900' msl - Regional run C, 500' agl 	<ul style="list-style-type: none"> - FRW2-FRE - FNE-FNW, FW2-FE2, and FE6-FW6 - 235 bearing from Lidar - FRE-FRW2
Aug 04	06	1417-1724	3.3	Clear, Winds 220/8 mps, Hot; PBL height: 2800' msl at 1440Z, 3500' at 1600Z, and 3200' at 1700Z, Altimeter 29.77	<ul style="list-style-type: none"> - Descent sounding 9500-2500' msl - Run along track-8 at 2500' msl - Full 8-line grid at 1600' msl, working south to north - Runs along track-1 at 3300 and 3100' msl - Full 8-line grid at 1600' msl, working north to south - Run along track-8 at 3100' msl 	<ul style="list-style-type: none"> - FW6-FE6 - 8 east/west lines (Fig. 6) - FW0-FE0 & FE0-FW0 - 8 east/west lines (Fig. 6) - FW6-FE6
Aug 04	07	1832-2127	3.0	Clear, Winds 190/7 mps, Hot; PBL height fairly constant at about 3100' msl, Altimeter 29.75	<ul style="list-style-type: none"> - Full 8-line grid at 1600' msl, working north to south - Runs on track-8 at 3100 and 2300' msl - Full 8-line grid at 1600' msl, working south to north - Run on track-1 at 3400' msl - Regional Run C at 500' agl - Control inputs at 95 knots, flaps 7 deg - Pitching inputs, 110 knots, flaps up 	<ul style="list-style-type: none"> - 8 east/west lines (Fig. 6) - FW6-FE6, FE6-FW6 - 8 east/west lines (Fig. 6) KA 20322 - FW0-FE0 - FRE-FRW2
Aug 06	08	1500-1831	3.7	Clear, Winds 060/5 mps at start, backing to 010 by end; PBL top: 2250' msl at 1520Z, 3100' at 1926Z, 3500' at 1635Z, 4000' at 1800Z, Altimeter 30.08	<ul style="list-style-type: none"> - Smooth runs and control inputs at 9500' - Descent sounding to 2000' msl - PBL runs along south edge, 2000' - L-pattern at 1600' msl - L-pattern at 2100' - L-pattern at 1600' - L-pattern at 2100' - L-pattern at 3200/3100' - L-pattern at 1600' - L-pattern at 3100' - L-pattern at 1600' - L-pattern at 1600' - L-pattern at 3500' - 2 Intercomparison runs with KingAir, 1900 and 1600' msl 	<ul style="list-style-type: none"> - FW6-FE6 - FE5-FW5, FS3-FN3 - FN3-FS3, FW5-FE5 - FE5-FW5, FS3-FN3 - FN3-FS3, FW5-FE5 - FE5-FW5, FS3-FN3 - FN3-FS3, FW5-FE5 - FE5-FW5, FS3-FN3 - FN3-FS3, FW5-FE5 - FE5-FW5, FS3-FN3 - FN3-FS3, FW5-FE5 - FE5-FW5, FS3-FN3 - FE5-FW5, FW5-FE5

TABLE 5 (cont): FIFE-89 FLIGHT SUMMARY - MAE TWIN OTTER

DATE	FLT #	GNT	HRS	WEATHER	RUNS FLOWN	LOCATION Waypoints
Aug 06	09	1929-2237	3.3	Mostly clear, a very few clouds, Winds N at 8-10 mps, becoming 020 at end of flight; PBL height: 5100' msl at 1935Z, 6000' at 2035, 5000' at 2200; Altimeter 30.10	<ul style="list-style-type: none"> - Run at 4800', 300' below top of PBL - Full 8-line grid, 1600' msl, working north to south - Run at 5700', 300' below top of PBL (KingAir FE5-FW6 same time) - Full 8-line grid, 1600' msl, working south to north - Run at 4800', 200' below top of PBL - Regional Run C at 500' agl 	<ul style="list-style-type: none"> - FE0-FW0 - 8 east/west lines, (Fig. 6) - FE6-FW6 - 8 east/west lines (Fig. 6) - FW0-FE0 - FRE-FRW2
Aug 07	10	1511-1848	3.8	Mostly clear, a few thin clouds at 6000' decreasing; Cool; Winds NNE at 7 mps, PBL top almost constant at 6000'; Apparent longwave air motions, Altimeter 30.25.	<ul style="list-style-type: none"> - Regional Run C, (unuseable due to computer halts); attempted intercomp with NOAA Long-Easy - Profile stack at 1600, 1900, 2900 and 5700' msl - Profile stack at 5700, 2900, 1900, 1650, 1650, 1900, 2900 and 5700' msl - Profile stack at 5700, 2900, 1900 and 1600' msl - Sounding to 8000' msl - Regional Run C at 500' agl (KingAir passes going other way) 	<ul style="list-style-type: none"> - FRW2-FRE - FE5-FW5 - FS2-FN2 - FE5-FW5 - FRE-FRW2
Aug 08	11	1512-1830	3.5	Clear to start, shallow clouds develop to 30%, Winds WNW and light; PBL height: 3100' at 1547Z, 4400' at 1608Z, 7000' at 1708Z, 7000' at 1746Z; Altimeter 30.15	<ul style="list-style-type: none"> - Regional Run C, 500 agl with Long Easy in loose formation - Run at 2900' msl - 8-line grid at 1600' msl, working north to south - Sounding climb to 7000' - Run at 6500', below top of PBL - 8-line grid at 1600' msl, working south to north - Run at 7000' below top of PBL 	<ul style="list-style-type: none"> - FRW2-FRE - FW0-FE0 - 8 east/west lines (Fig. 6) - FE6-FW6 - 8 east/west lines (Fig. 6) - FW0-FE0
Aug 08	12	1938-2209	2.7	Shallow clouds based at 7900', reducing from about 30 to 5 % coverage, Winds light from the WNW; PBL height 7900' through flight, Altimeter 30.11	<ul style="list-style-type: none"> - Run at 7500', below top of PBL - 4-line minigrid, Tracks 2, 4, 6 and 8 - Climb sounding to 8600' - Run at 7500', below top of PBL - 4-line minigrid, Tracks 8,6,4, and 2 - Run at 7500', below top of PBL - Regional Run C at 500' agl 	<ul style="list-style-type: none"> - FNE-FNW - 4 east/west lines (Fig. 6) - FE6-FW6 - 4 east/west lines (Fig. 6) - FNW-FNE - FRE-FRW2
Aug 10	13	1557-1938	3.8	Variable cloud, including Cu at 6000', middle cloud and Ci; Winds south 7-8 mps; PBL height: 6000' at 1635Z, 6800' at 1850Z; Altimeter 30.13	<ul style="list-style-type: none"> - Regional Run C at 500' - Sounding to 7200' msl - PBL run at 5700' msl - 8-line grid, 1600' msl, working north to south - PBL run at 6000' msl - Second grid at 1600' msl working south to north- computer intermittent after 6 th line - RTB 	<ul style="list-style-type: none"> - FRW2-FRE - FE0-FW0 - 8 east/west lines (Fig. 6) - FE6-FW6 - 6 east/west lines (Fig. 6)

TABLE 5 (cont): FIFE-89 FLIGHT SUMMARY - NAE TWIN OTTER

DATE	FLT #	GMT	HRS	WEATHER	RUNS FLOWN	LOCATION Waypoints
Aug 10	14	0052-0310 (Aug 11)	2.4	Mostly clear, South winds 8 mps; Sodar PBL top: 150m agl at 0118Z, 125m agl at 0146Z, 90m agl at 0208Z and 120m at 0230Z; Altimeter 30.11	- Night flight, descent sounding from 9500' - Racetrack pattern, pair of runs at 1800' msl - 5 pairs of runs at 1600' msl	- FW2-FE2, FNE-FNW - FW2-FE2, FNE-FNW
Aug 11	15	1619-2008	3.9	Variable cloud, a few Cu based 6200-6500' msl, Upper thin layer at 8700'; PBL height; 5200' msl at 1708Z, 5900' at 1733Z, 6200' at 1920Z; Variable PBL height; Winds south 8-9 mps; Altimeter 30.18	- Regional Run C at 500' agl in formation intercomparison with King Air - Sounding from 7000' - T-pattern; Profile stack at 1600, 1900, 2700 and 4800' msl - Profile stack at 5000, 2800, 1900, 1650, 1650, 1900, 2800 and 5000' msl - Profile stack at 5000, 2800, 1900 and 1600' msl - Sounding climb to 9200' msl - Regional Run C at 500' agl	- FRW2-FRE - FNW-FNE - FN2-FS2 - FNW-FNE - Over FIFE site - FRE-FRW2
Aug 12	16	1556-1959	4.2	Variable cloud, with Cu after 1700Z based at 6300' msl, PBL height: 4700' msl at 1643Z, 6300' at 1745Z, 6700' at 1900Z; Wind south 5 mps; Altimeter 30.13	- Regional Run C in formation with King Air, 500' agl - Sounding to 8000' msl - PBL run at 4300' msl - 8-line grid, 1600' msl, working north to south - PBL run at 6000' msl - 8-line grid, 1600' msl, working south to north - PBL run at 6300' msl - 2 Runs over Reservoir north of Manhattan, 200' agl - Regional Run C at 500' agl	- FRW2-FRE - FE0-FW0 - 8 east/west lines (Fig. 6) - FE6-FW6 - 8 east/west lines (Fig. 6) - FW0-FE0 - Reservoir - FRE-FRW2
Aug 14	-	1416-1655	2.7		- Transit, Salina-Peoria	
		1810-2058	2.8		- Transit, Peoria-London, Ont.	
		2206-2357	1.9		- Transit, London-Ottawa	

Total Flight Hours: 69.2

**TABLE 6: TWIN OTTER FLIGHT SUMMARY
TYPES AND NUMBERS OF RUNS**

Date Flt Hours				Flight Type Proj Test Tran		Number of Runs by Type'							
						Grid	L/T	Line	Lid	Comp	Reg	Sound	
Jul	20	-	5.5			X							
	21	0	2.7		X	X		2				1	
	24	-	0.6		X								
	25	-	0.6		X								
	26	-	0.6		X								
	27	01	3.0	X				16				1	2
		02	0.8	X								1	
	28	03	3.5	X			16			3		1	1
	31	-	0.5		X								
Aug	02	04	3.7	X				16		1		1	1
	03	05	2.7	X					3	4		2	
	04	06	3.3	X			16		3				1
		07	3.0	X			16		3			1	
	06	08	3.7	X				20	1		2		1
		09	3.3	X			16		3			1	
	07	10	3.8	X				16				2	1
	08	11	3.5	X			16		3			1	1
		12	2.7	X			8		3			1	1
	10	13	3.8	X			14		2			1	1
		14	2.4	X						10			1
	11	15	3.9	X				16			1	2	2
	12	16	4.2	X			16		5		1	2	1
	14	-	7.4			X							
	Totals				69.2		16		118 86 36 8 4 18 14				

'Types of Runs:

- Grid See Figure 4
- L/T L or T shaped profiling runs at several altitudes
- Line Other straight line runs, often to measure the top of the boundary layer
- Lidar Intercomparison runs over LIDAR
- Comp Intercomparison with NCAR King Air
- Reg Regional run to/from Salina
- Sound Sounding

TABLE 7 - INSTRUMENTATION PROBLEMS - TWIN OTTER - FIFE 1989

Date	Flight	Description
Jul 21	00	<ul style="list-style-type: none"> - Occasional event false event spike - Radiometers and PRT-5 use 1987 calibration - Licor self-calibration not correct on zero - Spikes and 2 deg shifts on Noseboom total and static temperatures, also 2 deg shift s to the VHF transmissions
Jul 24	-	<ul style="list-style-type: none"> - Event test; input induced event spikes, special jumper tests - Licor self cal doesn't reach zero at 135 knots - Spikes and steps on noseboom temperature, and affected by VHF transmissions
Jul 25	-	<ul style="list-style-type: none"> - Event test using PK9CFX and event circuitry bypassed - many serious problems after short of 15 volt power supply - no Loran on tape - HDGT is degrees magnetic - TASN B U/S because of PDNB and problem with airspeed switch circuitry - TTF and TTN purposely swapped at input to signal conditioning: proved that noise spikes on card, no probe: radio transmission problems on probe or installation - Licor doesn't get proper zero consistently; better at low airspeeds
Jul 26	-	<ul style="list-style-type: none"> - Noise spikes and steps on TTN and TSN; also 2 deg shifts with VHF transmissions - File 1 uses PK9CF1, in which raw event buffer replaces Litton latitude mintes on Channel 8; other two files OK using PK9CE1 or PK9CH1 - Licor uses 30 seconds for each gas; doesn't always get proper zero
Jul 27	01	<ul style="list-style-type: none"> - Litton winds and HDGTL not correct, possibly due to a wrong latitude on alignment; must use Doppler winds; WEP may be OK - L event shows when E event on; Causes YLAT =0 and error in corrected radiation when event marker on for programs before Aug 5 (inclusive). - Noise spikes and steps on TTN and TSN; also 2 deg shifts with radio transmissions - PRT-5, upward and downward radiometers use 1987 calibration. - Occasional spike on dew point - Bursts of spikes on various other parameters, including TTF,TSF, PSF, Dew Point, PDNB, PDF, (indicate a return of the Moosonee problem) - Licor fluxes don't agree well with ESRI. Pump may have started deterioration.
Jul 27	02	<ul style="list-style-type: none"> - L event shows when E event on; Causes YLAT =0 and errors in corrected RADUP readings for programs before August 05 (inclusive). - Noise spikes and steps on TTN and TSN; also 2 deg shifts with VHF transmissions - PRT-5, upward and downward radiometers use 1987 calibration. - Licor may not be reliable due to deteriorating pump
Jul 28	03	<ul style="list-style-type: none"> - L event shows when E event on: Causes YLAT=0 and errors in corrected RADUP in programs before August 05 (inclusive) - PRT-5, upward and downward radiometers use 1987 calibrations - Licor pump has broken diaphram; Licor not useable - TTN and TSN has 2 deg shifts due to VHF transmissions
Jul 31	-	<ul style="list-style-type: none"> - TTN and TSN spikes and steps for VHF transmission; Stepped off 1.5 deg for 8 minutes between two transmissions - Licor self cal not always to zero
Aug 02	04	<ul style="list-style-type: none"> - Licor self cal not always zero - TTN and TSN has steps due to radio transmissions - Probe heater switch off, TAS flashing at end run 02 - Haze lowers greenness index readings for higher altitude runs - Bad block of data, approximately 1522Z - Some spikes, evidence of the Moosonee problem

TABLE 7 (Cont)

Aug 03	05	<ul style="list-style-type: none"> - TTN and TSN have radio transmissio interference - Probe heater switch cycling for about 2 minutes after takeoff - Bad block of data about 1903Z
Aug 04	06	<ul style="list-style-type: none"> - TTN and TSN have radio transmission interference - Litton drifted 3 miles south - Computer halt at location 027336 at 1454Z; Message about stack overflow. Repeated this run, which was the first of the morning grid
Aug 04	07	<ul style="list-style-type: none"> - TTN and TSN have radio transmission interference - TAS, PSF disturbances at 2116Z during inputs. May be Moosonee problem. - LICOR U/S after 1919Z; tube from pump to analyzer disconnected - ESRI CO₂/H₂O analyzer nserviceable after 2105Z (last run) - Insect remains on noseboom probe; Alpha and beta appear OK in control inputs
Aug 06	08	<ul style="list-style-type: none"> - Computer halt at 162644Z - TTN and TSN have radion transmission interference - 2 mile Litton drift to south during flight
Aug 06	09	<ul style="list-style-type: none"> - Computer halt at 212218Z - TTN and TSN have radio transmission interference
Aug 07	10	<ul style="list-style-type: none"> - Computer halt at 152913Z and at 162501Z - Additional halt at about 1533 using older program PK9CF1 - TTN and TSN have radio transmission interference - Doppler VY problem at 1735Z (Run 13): VY wrong sign
Aug 08	11	<ul style="list-style-type: none"> - TTN and TSN radio interference - Some evidence of the Moosonee problem, spikes on parameters handled by original D/A circuitry
Aug 08	12	<ul style="list-style-type: none"> - Computer halt on taxi and just after takeoff; Recorder started at 1940Z, 2 minutes after takeoff - Reload program at 2048Z; 2 minute gap in recorded data - Doppler horizontal winds not correct on westerly headings: Doppler VY not going to negative readings when drift to left - TASNB spikes from at least 2054-2114Z, especially Runs 07-09: Causes spikes in Alpha, winds - Similar spikes in all parameters on original A/D; i.e, the Moosonee Problem
Aug 10	13	<ul style="list-style-type: none"> - Computer halts several times after 1836Z- Abort rest of flight - Moosonee spikes, possibly affecting computer - TTN and TSN radio interference
Aug 10	14	<ul style="list-style-type: none"> - TTN and TSN radio interference - No EOF on tape
Aug 11	15	<ul style="list-style-type: none"> - TTN and TSN radio interference - Doppler VY problem on Run 14; Doppler and Lit/Dop winds inaccurate for this run
Aug 12	16	<ul style="list-style-type: none"> - TTN and TSN radio interference - Doppler VY problem ,intermittent; Affects Doppler windson several runs - Licor self calibration not always to near zero - Greenness Index unserviceable from 1628-1645Z, i.e. near end of second segment of first regional run

TABLE 8: FORMAT FOR DATA ARCHIVE - FIFE 89

Each file consists of 8 lines of data for each flux run. The first line gives flight and run identification. This is followed by seven data lines, which will be described below along with the formats used. Data from the three flux aircraft will be in this format. Unavailable data will be replaced by a string of 9's.

LINE#	GROUP	PARAMETERS	UNITS	FORMAT	COMMENTS
1	IDENT	' NAE'	-	A4	- IDENTIFIES NAE TWIN OTTER
		FLIGHT DATE, YYMMDD	-	1X,A6	- FLIGHT DATE
		MISSION OF DAY, EG ' MISSION 1/2	-	A12	- FLIGHT OF THE DAY
		RUN NUMBER	-	1X,A6	- NAE RUN NUMBER
2	TIME, LOCATION & RUN MEANS	RUN START TIME	CDT	1X,611	
		"	GMT	1X,611	
		STARTING LATITUDE	DEG,MIN	F7.1	- EG, ' 4357.2'
		STARTING LONGITUDE	"	F7.1	
		RUN END TIME	CDT	1X,611	
		ENDING LATITUDE	DEG, MIN	F7.1	
		ENDING LONGITUDE	"	F7.1	
		AIRCRAFT HEADING, TRUE	DEG TRUE	F5.0	
		MEAN PRESSURE ALTITUDE	M	F6.0	- ADJUSTED FOR ALTIMETER SETTING
		MEAN RADAR ALTITUDE	M	F6.0	
		MEAN TEMP	DEG C	F7.2	- FROM TSC (CH 36)
		MEAN POTENTIAL TEMPERATURE	DEG K	F7.2	- CALC FROM TSC AND PSNBC
		MEAN MIXING RATIO	GM/KG	F6.2	- CALC FROM DEW POINT, TSC & PSNBC GM OF H2O PER KG DRY AIR
		MEAN NORTH/SOUTH WIND, + FROM SOUTH	M/S	F7.2	- NEGATIVE OF UGE (CH 16 ABOVE)
		MEAN EAST/WEST WIND, + FROM WEST	M/S	F7.2	- NEGATIVE OF VGE (CH 17 ABOVE)
		MEAN PRESSURE	MB	F7.1	- PSNBC (CH 35)
		MEAN PRT-5 SURFACE TEMP	DEG C	F5.1	- CH 25
		MEAN DOWNWELLING RADIATION	W/M2	F6.0	- CH 26 (INCIDENT)
		MEAN UPWELLING RADIATION	W/M2	F5.0	- CH 27 (REFLECTED)
		MEAN GREENNESS INDEX	-	F5.2	- CH 37
3	RMS ASSOCIATED WITH ABOVE MEANS	RMS TEMPERATURE	DEG C	F5.2	
		RMS POTENTIAL TEMP	DEG K	F5.2	
		RMS MIXING RATIO	GM/KG	F5.2	- FROM DEW POINT, TSC AND PSNBC
		RMS NORTH/SOUTH WIND	M/S	F5.2	
		RMS EAST/WEST WIND	M/S	F5.2	
		RMS PRESSURE	MB	F4.1	
		RMS SURFACE TEMPERATURE	DEG C	F5.1	
		RMS DOWNWELLING RADIATION	W/M2	F5.0	
		RMS UPWELLING RADIATION	W/M2	F5.0	
		RMS GREENNESS INDEX	-	F5.2	

TABLE 8 (cont)

4 LINEAR TRENDS	TREND IN TEMPERATURE	DEG C/M	1X,E10.3	- TREND PER METER (GROUND SPEED)
	TREND IN POTENTIAL TEMP	DEG K/M	E10.3	
	TREND IN MIXING RATIO	GM/KG/M	E10.3	- DERIVED FROM DEW POINT
	TREND IN NORTH/SOUTH WIND	M/S/M	E10.3	
	TREND IN EAST/WEST WIND	M/S/M	E10.3	
	TREND IN PRESSURE	MB/M	E10.3	
	TREND IN SURFACE TEMPERATURE	DEG C/M	E10.3	
	TREND IN DOWNWELLING RADIATION	W/M2/M	E10.3	
	TREND IN UPWELLING RADIATION	W/M2/M	E10.3	
	TREND IN GREENNESS INDEX	1/M	E10.3	
5 RMS TURBULENT *UNFILTERED*	RMS VERTICAL GUST VELOCITY	M/S	F5.2	- WGE, DOPPLER/INERTIAL WIND
	RMS NORTH/SOUTH GUST VELOCITY	M/S	F5.2	- UGE
	RMS EAST/WEST GUST VELOCITY	M/S	F5.2	- VGE
	RMS ALONG-WIND COMPONENT	M/S	F5.2	- ALONG RUN-MEAN WIND DIRECTION
	RMS ACROSS WIND COMPONENT	M/S	F5.2	- ACROSS RUN-MEAN WIND DIRECTION
	RMS POTENTIAL TEMPERATURE	DEG K	F5.2	
	RMS H2O MIXING RATIO (H2O ANALYZER) GM/KG		F5.2	- NOTE** FROM H2O ANALYZER IN DUCT DERIVED FROM CH 29, 34 AND 24
	RMS CO2 MIXING RATIO (CO2 ANALYZER) MG/KG		F5.2	- MG OF CO2 PER KG DRY AIR IN DUCT DERIVED FROM CH 28, 24, 34 AND 29
6 RMS TURBULENT * FILTERED*	SAME 8 PARAMETERS AS ABOVE, BUT HIGH PASS FILTERED AT 5 KM WAVELENGTH (SEE NOTE 1)		"	
7 FLUXES *FILTERED* (NOTE 2)	NORTH/SOUTH MOMENTUM FLUX	N/M2	F6.2	- POSITIVE WIND FROM SOUTH
	EAST/WEST MOMENTUM FLUX	N/M2	F6.2	- POSITIVE WIND FROM WEST
	MOMENTUM FLUX ALONG MEAN WIND DIRECTION	N/M2	F6.2	- THE TRADITIONAL UW
	MOMENTUM FLUX ACROSS " "	N/M2	F6.2	- THE TRADITIONAL VW
	SENSIBLE HEAT FLUX	W/M2	F6.0	- FROM WGE & POTENTIAL TEMP
	LATENT HEAT FLUX	W/M2	F6.0	- FROM H2O ANALYZER
	CARBON DIOXIDE FLUX	KG/HA/H	F6.1	- KILOGRAMS PER HECTARE PER HOUR
8 CORRELATION	CORRELATION COEFFICIENTS FOR THE ABOVE 7 PARAMETERS		ALL F6.2	
	PLUS, CC FOR MIXING RATIO*POTENTIAL TEMP		F6.2	

** NOTE : THE FLUXES WERE DERIVED FROM HIGH-PASS FILTERED DATA USING A BREAKPOINT OF 0.012 HZ, WHICH CORRESPONDS TO A WAVELENGTH OF APPROXIMATELY 5 KM.

TABLE 9: TWIN OTTER DATA - FIFE-89

The data presented in each column of the following tables are described below:

Column Heading	Units	Explanation
<u>Run Averages</u>		
ST GMT	-	Greenwich Mean Time at the start of the run (Central Daylight Time plus 5 hours)
SEC	sec	Duration of the run
DIST	km	Length of the run (integrated ground speed)
PALT	m	Pressure altitude above sea level (has been corrected for altimeter setting)
RALT	m	Radio altimeter height above the ground
TEMP	deg C	Static temperature
DEWPT	deg C	Dew point temperature
PRT5	deg C	Surface temperature
GRN	-	Greenness Index from Skye Industries sensor
RADUP	$W\ m^{-2}$	Incident radiation from Kipp and Zonen CM-11, corrected for aircraft attitude angles
LICOR	$mg\ m^{-3}$	CO ₂ mean concentration from LI-COR slow-response analyzer, uncorrected
HDG HDGL	deg T	Aircraft true heading from C-12 compass; from Litton IRS
WIND, WINDLD	deg T ms^{-1}	Mean wind direction and wind speed; WINDLD from LIT/DOP winds
<u>RMS</u>		RMS of fluctuations in:
UGE UGEL	ms^{-1}	North/south wind component, UGE from NAE/DOP winds, UGEL from Litton Winds
VGE VGEL	ms^{-1}	East/west wind component, VGE from NAE/DOP winds, VGEL from Litton Winds
WGE WEP	ms^{-1}	Vertical wind component; WGE from NAE/DOP winds, WEP from Litton winds
TS	deg C	Temperature
CO2	$mg\ m^{-3}$	CO ₂ from fast-response ESRI Analyzer
H2O	$g\ m^{-3}$	H ₂ O from fast-response ESRI analyzer
<u>Fluxes</u>		
WT	$W\ m^{-2}$	Sensible heat flux
WC	kg/h·hr	CO ₂ flux in kilograms per hectare per hour (36 times the flux in $mg\cdot m^{-2}$ per second)
WQ	$W\ m^{-2}$	Latent heat flux (water vapour)
UW	$N\ m^{-2}$	Momentum flux
Z/L	-	Stability parameter, height above ground divided by the Obukhov Scale Length

FUSELAGE TEMPERATURE DATA USED; FILTERED AT 0.01200

RUN AVERAGES														RMS				CORRECTED FLUXES									
ST	GMT	SEC	DIST	PALT	RALT	TEMP	DEWPT	PRTS	GRN	RADUP	LIC08	H0G	WIND	UGE	VGE	WGE	TS	CO2	H2O	WT	WC	WQ	UW	Z/L			
			km	m	m	degC	degC	degC	W/m ²	U/m ²	mg/m ³	T	T	ms ⁻¹	ms	ms	degC	mg/m ³	gm/m ³	U/m ²	kg/hh	U/m ²	N/m ²				
REGIONAL RUN B, 500 ' AGL																											
153730.	536.	35.52	529.	166.	24.80	18.46	36.5	1.33	645.	595.9	071	223	4.7	0.79	0.82	0.98	0.14	1.1	0.17	93.	-5.2	191.	-0.17	-3.4			
154633.	543.	37.56	550.	163.	25.16	18.44	33.4	1.78	608.	588.8	074	235	5.5	0.90	0.88	0.95	0.18	1.3	0.14	97.	-12.9	160.	-0.26	-1.9			
PROFILING STACKS, T-PATTERN																											
EAST/WEST FNV3-FNE3																											
16 525.	317.	15.95	500.	100.	26.07	18.68	35.1	1.93	730.	590.2	267	234	5.3	0.92	0.93	0.79	0.17	1.4	0.15	90.	-11.8	168.	-0.11	-3.9			
161254.	273.	15.95	586.	194.	25.26	18.30	35.3	1.87	769.	583.4	095	234	6.3	0.83	0.87	0.85	0.12	1.1	0.14	63.	-10.4	87.	0.03	37.3			
1620 4.	312.	15.69	803.	412.	23.15	17.64	34.7	1.87	772.	567.7	266	235	5.1	0.78	0.76	0.95	0.07	0.9	0.19	12.	-4.3	146.	0.04	13.4			
1628 8.	261.	15.85	1227.	830.	19.23	16.17	33.2	1.72	780.	539.3	094	237	6.0	0.68	0.78	0.67	0.16	0.9	0.47	-3.	0.9	115.	-0.13	-1.3			
173929.	278.	15.35	1602.	1205.	16.69	14.79	35.2	1.68	785.	513.8	268	218	4.2	0.73	0.92	0.70	0.16	0.6	0.23	-9.	0.2	57.	0.06	-3.9			
174644.	260.	15.99	841.	450.	24.27	16.59	39.3	1.81	830.	562.9	097	235	5.6	0.93	1.03	1.12	0.10	0.9	0.11	69.	-9.6	131.	0.13	10.8			
175320.	295.	15.75	599.	197.	26.84	16.99	37.9	1.85	696.	579.5	269	225	4.4	0.97	0.83	0.97	0.13	1.1	0.12	90.	-11.3	105.	-0.10	-8.1			
18 016.	254.	15.48	508.	105.	27.88	17.18	39.2	1.89	788.	585.8	096	230	5.0	0.98	0.86	0.82	0.19	1.2	0.15	104.	-10.6	132.	-0.10	-4.9			
NORTH/SOUTH FN2-FS2																											
163852.	307.	16.70	1318.	911.	18.55	15.83	33.1	1.78	723.	533.2	184	238	5.0	0.75	0.76	0.76	0.16	0.8	0.50	-17.	1.4	244.	-0.13	-0.1			
164614.	290.	17.22	802.	402.	23.76	17.28	36.2	1.88	760.	567.1	000	230	5.2	0.74	0.94	1.13	0.11	1.1	0.19	72.	-11.0	226.	-0.15	-8.2			
1653 3.	315.	17.14	590.	185.	26.09	17.49	35.6	1.91	631.	580.8	189	244	5.1	0.93	0.99	0.98	0.15	1.3	0.26	100.	-15.5	297.	-0.21	-3.1			
17 0 2.	282.	16.67	507.	94.	27.09	17.60	36.0	1.95	671.	585.4	001	228	4.6	1.11	0.99	0.85	0.21	1.6	0.24	102.	-15.3	257.	-0.05	-15.0			
17 638.	321.	16.84	531.	122.	26.95	17.48	37.7	1.94	779.	582.8	187	243	4.4	1.17	1.08	0.93	0.15	1.3	0.16	90.	-16.0	172.	-0.18	-2.2			
1714 8.	278.	16.25	587.	177.	26.48	17.19	37.1	1.97	700.	578.4	000	231	5.1	1.17	0.88	1.00	0.16	1.3	0.20	118.	-18.7	241.	-0.11	-8.6			
172143.	316.	16.86	802.	402.	24.35	16.64	36.1	1.86	744.	563.4	189	243	4.6	0.92	1.02	1.22	0.09	1.1	0.19	56.	-12.7	248.	-0.13	-8.6			
173028.	275.	16.48	1329.	922.	19.21	15.14	34.5	1.76	747.	529.8	001	228	5.0	0.88	0.83	0.88	0.09	0.9	0.24	-9.	1.7	165.	0.24	0.2			

TABLE 9(a): TWIN OTTER DATA - FIFE89 FLIGHT 01 - 27 JULY, 1989

NAE C-FPOK , FILE 1ARC FIFE89 (01 AUG 89), FLIGHT DAT 27-JUL-89 PRINT DATE 01-AUG-89 FIFE-02, PRINT 2, REGIONAL RUN C
 FUSELAGE TEMPERATURE DATA USED; FILTERED AT 0.01200

RUN AVERAGES														RMS				CORRECTED FLUXES								
ST	GMT	SEC	DIST	PALT	RALT	TEMP	DEUPT	PRT5	GRN	RADUP	LICOR	HDGL	WINDLD	UGEL	VGEL	WEP	TS	CO2	H2O	WT	WC	WQ	UM	Z/L		
			km	m	m	degC	degC	degC	W/m ²	mg/m ³	T	T	ms ⁻¹	ms ⁻¹	ms ⁻¹	degC	degC	mg/m ³	gm/m ³	W/m ²	kg/hh	W/m ²	W/m ²	N/m ²		
REGIONAL RUN C																										
191823.	657.	40.08	575.	163.	28.09	16.73	42.8	1.66	721.	581.4	235	200	5.5	1.04	1.11	1.10	0.21	1.1	0.14	163.	-7.3	117.	-0.14	-7.0		
192927.	643.	38.74	557.	158.	28.17	16.87	43.2	1.47	744.	583.4	235	190	6.5	1.04	1.16	1.10	0.20	1.1	0.14	140.	-11.9	183.	-0.21	-3.4		

TABLE 9(b): TWIN OTTER DATA - FIFE89 FLIGHT 02 - 27 JULY, 1989

FUSELAGE TEMPERATURE DATA USED; FILTERED AT 0.01200

RUN AVERAGES														RMS			CORRECTED FLUXES							
ST	GMT	SEC	DIST	PALT	RALT	TEMP	DEWPT	PRTS	GRN	RADUP	LICOR	HDGL	WINDLD	UGEL	VGEL	WEP	TS	CO2	H2O	WT	WC	WQ	WJ	Z/L
			km	m	m	degC	degC	degC	W/m ²	W/m ²	mg/m ³	T	T	ms ⁻¹	ms ⁻¹	degC	mg/m ³	gm/m ³	gm/m ³	W/m ²	kg/hh	W/m ²	W/m ²	N/m ²
CONTROL INPUTS, 9500'																								
145453.	23.	1.57	2932.	*	10.10	-0.71	30.1	1.16	570.	*	082	188	6.7	0.06	0.13	0.13	0.02	0.4	0.08	-1.	0.1	-5.	0.00	-464.3
145523.	18.	1.24	2934.	*	10.04	-0.14	29.9	1.15	578.	*	082	184	6.4	0.53	0.11	0.09	0.02	0.7	0.08	0.	-0.7	-6.	0.01	-12.0
145546.	17.	1.16	2932.	*	9.72	1.62	28.4	1.15	582.	*	080	182	7.0	0.15	0.08	0.05	0.03	0.4	0.13	0.	-0.1	2.	0.00	14.8
LIDAR INTERCOMP, 235 MAG HEADING																								
151210.	300.	18.16	544.	160.	25.61	18.28	34.0	1.84	618.	*	234	198	4.2	0.83	0.73	0.85	0.12	1.1	0.21	71.	-6.3	232.	-0.11	-5.3
152347.	281.	17.26	859.	485.	22.61	17.36	33.8	1.75	648.	*	237	196	4.3	0.76	0.71	1.09	0.13	0.9	0.45	50.	-2.6	407.	-0.32	-2.9
153511.	274.	17.38	1228.	849.	19.71	14.77	33.6	1.65	687.	*	236	186	5.5	0.77	0.75	0.66	0.34	1.6	0.94	-64.	11.2	517.	-0.13	6.2
GRID A, WORKING SOUTH TO NORTH, 1600' MSL																								
154359.	274.	15.59	495.	76.	26.53	18.46	35.2	2.06	680.	*	093	195	4.7	0.90	1.00	0.83	0.19	1.5	0.26	111.	-16.9	284.	-0.14	-2.6
155024.	296.	16.42	495.	79.	26.63	18.39	35.2	2.12	698.	*	264	184	4.3	0.90	1.01	0.81	0.17	1.7	0.29	101.	-17.4	251.	-0.21	-1.3
155740.	282.	15.90	498.	89.	26.71	18.36	34.6	2.25	704.	*	093	188	4.5	0.82	1.01	0.76	0.15	1.5	0.25	73.	-17.1	221.	-0.17	-1.5
16339.	288.	15.90	494.	92.	26.98	18.39	35.7	2.12	723.	*	263	178	4.4	1.00	1.15	0.89	0.19	2.3	0.30	135.	-22.3	274.	-0.26	-1.5
161034.	289.	15.95	493.	85.	27.10	18.38	37.2	1.84	730.	*	094	183	5.1	0.94	1.00	0.87	0.19	1.7	0.28	120.	-22.5	271.	-0.15	-2.8
161652.	290.	15.84	496.	96.	27.09	18.23	37.0	2.05	749.	*	262	169	4.5	0.73	1.06	0.82	0.16	1.3	0.21	92.	-14.0	212.	-0.04	-19.6
162326.	293.	15.81	496.	104.	27.23	18.17	38.5	1.93	755.	*	093	181	4.9	0.82	0.98	0.84	0.17	1.2	0.19	96.	-14.9	179.	-0.07	-7.7
162955.	281.	15.85	496.	125.	27.37	18.08	38.6	1.89	770.	*	264	169	4.7	0.83	1.14	0.98	0.19	1.4	0.18	149.	-18.6	220.	-0.11	-7.7
GRID B, WORKING NORTH TO SOUTH, 1600' MSL																								
163616.	283.	15.63	501.	130.	27.42	17.98	40.6	1.73	778.	*	093	176	5.2	0.88	1.10	1.00	0.18	1.2	0.29	137.	-15.4	181.	-0.06	-16.4
164251.	280.	15.63	505.	103.	27.32	18.15	39.1	1.93	794.	*	262	168	5.2	0.85	1.07	0.88	0.19	1.2	0.19	115.	-14.1	155.	-0.10	-5.7
164913.	287.	15.72	507.	107.	27.38	18.26	39.2	1.97	802.	*	094	174	5.0	0.94	1.07	0.96	0.19	1.3	0.23	122.	-16.8	220.	-0.11	-5.7
165525.	278.	15.61	508.	100.	27.31	18.14	39.4	1.83	759.	*	262	168	4.8	0.93	1.05	0.87	0.16	1.4	0.21	105.	-19.0	241.	-0.24	-1.4
17142.	275.	15.06	505.	91.	27.38	18.23	39.1	2.01	835.	*	092	171	5.0	1.00	1.07	0.90	0.17	1.6	0.21	95.	-20.5	255.	-0.11	-3.9
17186.	290.	16.09	507.	92.	27.49	18.31	39.7	2.19	844.	*	264	163	4.4	0.94	1.20	0.88	0.20	1.5	0.22	122.	-18.1	204.	-0.17	-2.4
171414.	306.	16.23	504.	88.	27.64	18.38	40.4	1.98	811.	*	093	170	4.9	1.11	1.11	0.90	0.22	1.5	0.23	134.	-18.2	230.	-0.26	-1.3
172110.	273.	15.15	508.	83.	27.57	18.30	40.8	2.00	828.	*	264	162	5.0	0.85	1.09	0.94	0.21	1.4	0.28	124.	-13.3	213.	-0.13	-3.6
REGIONAL RUN C, 500' AGL																								
173226.	633.	39.73	572.	159.	27.34	17.81	43.9	1.72	819.	*	235	164	5.0	0.98	1.22	1.19	0.21	1.2	0.21	190.	-11.5	216.	-0.10	-14.2
17439.	633.	39.00	560.	164.	27.32	18.32	43.9	1.52	802.	*	235	171	5.6	1.03	1.26	1.17	0.19	1.1	0.20	169.	-12.2	247.	-0.19	-4.8

TABLE 9(c): TWIN OTTER DATA - FIFE89 FLIGHT 03 - 28 JULY, 1989

FUSELAGE TEMPERATURE DATA USED; FILTERED AT 0.01200

RUN AVERAGES														RMS			CORRECTED FLUXES									
ST	GMT	SEC	DIST	PALT	RALT	TEMP	DEWPT	PRT5	GRN	RADUP	LICOR	HDGL	WINDLD	UGEL	VGEL	WEP	Ts	CO2	H2O	WT	WC	WQ	WV	Z/L		
			km	m	m	degC	degC	degC	W/m ²	W/m ²	mg/m ³	T	T	ms ⁻¹	ms ⁻¹	degC	mg/m ³	gm/m ³	W/m ²	kg/hh	W/m ²	W/m ²	N/m ²			
NORTH/SOUTH RUNS, FS3-FN3																										
1600' MSL																										
152631.	203.	12.74	531.	146.	24.31	20.66	30.2	1.63	577.	597.1	000	168	8.3	1.41	0.55	0.65	0.08	1.0	0.11	33.	-6.8	82.	0.12	1.8		
155516.	232.	13.90	502.	119.	25.08	20.73	32.3	1.72	559.	596.9	002	165	6.9	0.73	0.68	0.87	0.15	1.3	0.16	99.	-21.6	230.	-0.29	-1.2		
164416.	309.	15.30	506.	125.	25.96	20.78	32.8	1.67	487.	592.4	176	159	6.1	0.90	1.11	0.91	0.18	1.5	0.17	117.	-17.9	169.	-0.16	-3.3		
171235.	322.	15.05	506.	122.	26.37	20.73	31.6	1.59	407.	590.4	177	167	6.3	0.76	0.73	0.76	0.11	1.2	0.13	56.	-12.3	80.	-0.17	-1.4		
200' BELOW CLOUD BASE																										
154640.	294.	14.46	802.	425.	21.92	20.08	30.5	1.55	538.	577.0	182	172	6.3	0.63	0.74	0.82	0.10	0.8	0.18	-2.	-2.0	120.	-0.02	-15.1		
161541.	300.	14.94	804.	433.	22.31	20.13	31.0	1.55	527.	574.8	176	166	6.0	0.77	0.73	0.80	0.09	1.0	0.19	17.	-8.4	103.	-0.03	-26.6		
162352.	226.	13.86	864.	490.	21.98	19.85	32.5	1.55	748.	570.4	003	167	7.2	0.77	0.75	0.77	0.12	0.9	0.24	-4.	-5.1	161.	-0.07	-2.5		
165343.	231.	14.63	927.	553.	21.83	19.76	31.1	1.49	540.	563.9	002	169	7.6	0.79	0.69	0.86	0.08	1.1	0.16	28.	-11.7	149.	-0.16	-4.8		
EAST/WEST RUNS, FNU-FNE																										
1600' MSL																										
153158.	299.	15.44	504.	118.	24.76	20.93	27.5	1.90	355.	596.2	097	176	7.4	0.76	1.53	0.73	0.12	1.5	0.16	66.	-17.6	151.	-0.24	-1.0		
16 051.	303.	15.49	505.	117.	24.79	20.96	30.5	1.98	613.	596.7	095	168	6.5	0.75	0.86	0.78	0.16	1.6	0.13	96.	-22.2	150.	-0.25	-1.4		
163734.	269.	15.36	508.	113.	25.12	20.87	30.5	1.97	548.	593.9	262	153	6.6	0.83	0.77	0.75	0.13	1.5	0.18	65.	-18.7	143.	-0.20	-1.3		
17 625.	276.	15.43	508.	111.	25.94	20.85	32.6	2.00	659.	589.7	261	157	7.0	0.90	1.03	0.98	0.17	2.0	0.19	111.	-31.7	301.	-0.31	-1.2		
200' BELOW CLOUD BASE																										
153955.	281.	15.30	802.	419.	21.75	20.08	27.2	1.70	423.	575.9	260	169	7.0	0.50	0.58	0.64	0.11	0.8	0.22	-15.	1.3	139.	-0.03	4.6		
16 9 8.	283.	15.62	804.	420.	21.85	20.13	28.4	1.72	459.	576.0	262	165	6.6	0.68	0.74	0.78	0.09	1.0	0.20	7.	-6.9	140.	-0.11	-2.8		
162952.	301.	15.94	864.	488.	21.57	19.80	29.6	1.67	602.	571.4	096	168	7.4	0.68	0.68	0.62	0.10	1.1	0.22	-6.	-5.3	152.	-0.12	-0.7		
165953.	276.	15.16	921.	548.	21.67	19.60	31.3	1.74	727.	563.1	096	172	7.7	1.12	0.76	0.72	0.12	1.4	0.29	-12.	-12.2	175.	-0.36	0.0		
LIDAR RUN, 205 MAG, 3400' MSL																										
173654.	392.	18.79	1053.	665.	21.40	18.84	32.3	1.64	710.	552.9	204	170	8.9	0.74	0.74	0.68	0.12	1.4	0.31	-10.	-2.6	47.	0.06	-4.7		
REGIONAL RUN C, 500' AGL																										
175130.	628.	39.02	579.	171.	26.37	20.22	33.2	1.80	652.	582.4	231	161	8.6	0.94	0.93	0.99	0.15	1.6	0.20	97.	-21.0	253.	-0.35	-1.3		
18 2 4.	659.	39.75	554.	160.	27.08	20.36	36.5	1.42	605.	583.9	231	161	9.0	0.90	0.99	1.01	0.16	1.5	0.18	121.	-20.3	210.	-0.31	-1.7		

TABLE 9(d): TWIN OTTER DATA - FIFE89 FLIGHT 04 - 02 AUGUST, 1989

FUSELAGE TEMPERATURE DATA USED; FILTERED AT 0.01200

RUN AVERAGES														RMS		CORRECTED FLUXES										
ST	GHT	SEC	DIST	PALT	RALT	TEMP	DEWPT	PRTS	GRN	RADUP	LICOR	HDGL	WINDLD	UGEL	VGEL	WEP	TS	CO2	H2O	WT	WC	WQ	UM	Z/L		
			km	m	m	degC	degC	degC	degC	W/m ²	mg/m ³	T	T	ms ⁻¹	ms ⁻¹		degC	mg/m ³	gm/m ³	W/m ²	kg/hh	W/m ²	N/m ²			
3 FAMILIARIZATION RUNS, FNE-FNW, FW2-FE2 AND FE6-FW6																										
174931.	314.	15.55	492.	103.	25.89	21.01	28.4	2.03	523.	597.6	259	208	9.7	1.00	0.90	0.82	0.10	1.5	0.21	49.	-13.3	184.	-0.31	-0.5		
175637.	273.	16.05	496.	99.	25.99	21.10	29.1	1.99	621.	597.4	097	209	10.4	1.12	1.12	0.81	0.12	1.6	0.18	47.	-18.0	191.	-0.39	-0.3		
18 510.	346.	16.25	493.	81.	26.49	20.72	30.0	2.14	707.	596.2	258	211	10.4	1.15	0.98	0.84	0.16	1.6	0.21	84.	-15.2	252.	-0.39	-0.5		
LIDAR RUNS, 235 BEARING																										
1817 7.	226.	10.23	856.	490.	23.00	19.77	30.0	1.77	825.	571.8	233	213	10.6	0.77	0.81	0.87	0.08	0.9	0.23	8.	0.8	230.	-0.30	-1.0		
182558.	416.	19.03	852.	482.	23.32	19.86	32.8	1.63	818.	571.0	236	213	10.7	0.75	0.79	0.83	0.08	0.8	0.18	14.	-0.6	150.	-0.14	-3.2		
184038.	410.	18.83	500.	117.	27.23	20.76	35.6	1.74	856.	593.9	234	208	10.0	1.03	0.92	0.88	0.16	1.3	0.16	94.	-10.9	197.	-0.40	-0.7		
185453.	401.	18.72	1198.	825.	20.61	18.69	32.5	1.52	828.	546.6	237	217	9.6	0.64	0.70	0.58	0.26	1.4	0.47	-10.	0.9	137.	-0.03	-0.1		
REGIONAL RUN C, WEST TO EAST, 500' AGL																										
172519.	541.	39.27	540.	161.	25.72	19.82	36.0	1.42	752.	600.1	064	209	11.0	1.02	0.96	1.07	0.16	1.3	0.15	112.	-13.4	209.	-0.33	-1.5		
173433.	539.	38.77	554.	160.	25.03	20.57	29.3	1.94	625.	596.9	064	209	10.6	0.94	0.90	0.84	0.11	1.3	0.21	53.	-11.5	226.	-0.35	-0.7		
REGIONAL RUN C, EAST TO WEST, 500' AGL																										
19 940.	729.	39.49	569.	164.	26.99	20.68	33.6	1.86	756.	587.4	233	207	10.4	1.01	0.89	0.97	0.12	1.3	0.15	71.	-12.3	171.	-0.30	-1.1		
192159.	732.	40.11	547.	158.	27.53	20.91	39.9	1.44	753.	588.4	233	199	10.6	1.14	1.17	1.14	0.17	1.4	0.15	141.	-13.6	205.	-0.41	-1.3		

TABLE 9(e): TWIN OTTER DATA - FIFE89 FLIGHT 05 - 03 AUGUST, 1989

FUSELAGE TEMPERATURE DATA USED; FILTERED AT 0.01200

RUN AVERAGES														RMS			CORRECTED FLUXES								
ST	GMT	SEC	DIST	PALT	RALT	TEMP	DEWPT	PRT5	GRN	RADUP	LTCOR	HDGL	WINDLD	UGEL	VGEL	WEP	TS	CO2	H2O	WT	WC	WQ	UW	Z/L	
			km	m	m	degC	degC	degC	W/m ²	W/m ²	mg/m ³	T	T	ms ⁻¹	ms ⁻¹		degC	mg/m ³	gm/m ³	W/m ²	kg/hh	W/m ²	N/m ²		
UPPER RUN , TRACK-8, 2500'																									
1443	0.	251.	15.56	778.	375.	23.75	18.08	27.5	2.09	513.	575.4	098	228	10.3	0.69	0.90	0.48	0.20	0.8	0.27	-18.	0.3	50.	-0.10	2.2
FULL 8-LINE GRID, 1600' MSL, WORKING SOUTH TO NORTH																									
145822.	267.	15.60	504.	87.	26.61	19.14	29.0	2.27	544.	591.3	096	219	8.7	0.81	0.84	0.79	0.13	1.4	0.16	65.	-19.5	201.	-0.34	-0.5	
15 435.	328.	15.97	504.	90.	26.69	19.15	29.0	2.33	571.	590.7	263	219	7.8	0.90	0.76	0.72	0.10	1.4	0.15	39.	-12.2	142.	-0.25	-0.5	
151136.	265.	15.63	505.	100.	26.77	19.19	29.0	2.46	578.	589.6	095	223	8.2	0.87	0.90	0.70	0.11	1.5	0.17	33.	-15.6	151.	-0.26	-0.4	
151819.	340.	16.56	504.	101.	26.92	19.28	29.5	2.34	605.	588.7	263	223	7.2	0.86	0.80	0.73	0.11	1.8	0.19	45.	-19.9	202.	-0.21	-0.8	
152560.	290.	16.11	504.	99.	27.04	19.35	30.8	2.08	615.	588.2	096	221	8.0	0.82	0.73	0.73	0.11	1.5	0.29	51.	-16.8	157.	-0.29	-0.5	
153324.	323.	15.77	506.	107.	27.13	19.42	31.2	2.24	641.	587.5	264	218	7.4	0.77	0.82	0.75	0.13	1.3	0.14	54.	-10.1	143.	-0.20	-1.1	
154029.	268.	15.49	506.	119.	27.29	19.47	31.9	2.08	651.	587.0	096	218	8.3	0.79	0.84	0.83	0.14	1.2	0.13	68.	-14.0	158.	-0.17	-1.9	
154649.	330.	15.86	505.	141.	27.41	19.44	33.8	1.99	672.	586.9	263	219	7.4	0.87	0.78	0.82	0.14	1.1	0.13	70.	-12.6	158.	-0.24	-1.3	
UPPER LEVEL RUNS, TRACK-1, 3300 AND 3100'																									
155858.	253.	15.48	1025.	680.	24.71	17.24	33.2	1.65	718.	554.7	089	273	5.9	0.82	0.60	0.60	0.52	4.0	0.24	36.	4.1	-1.	-0.06	-21.5	
16 547.	365.	17.94	959.	613.	24.09	18.03	33.7	1.78	734.	558.3	268	252	6.0	0.94	0.61	0.53	0.29	1.0	0.26	-39.	-0.6	59.	-0.02	102.7	
FULL 8-LINE GRID, 1600' MSL, WORKING NORTH TO SOUTH																									
161449.	283.	16.14	506.	141.	28.10	19.65	36.9	1.75	735.	585.7	096	216	7.6	0.75	1.00	0.93	0.18	1.4	0.15	95.	-20.7	231.	-0.22	-2.0	
1621 2.	315.	15.49	505.	108.	28.16	19.75	35.0	2.07	746.	584.9	261	212	6.9	0.78	0.74	0.77	0.16	1.5	0.18	68.	-15.8	193.	-0.13	-2.6	
162737.	264.	15.23	509.	112.	28.28	19.73	34.9	2.10	756.	584.5	096	216	7.7	0.80	0.91	0.78	0.13	1.6	0.16	43.	-14.2	145.	-0.24	-0.7	
163341.	328.	15.91	508.	101.	28.44	19.80	35.2	2.07	767.	583.6	262	214	6.9	0.81	0.86	0.78	0.16	1.8	0.20	64.	-25.1	242.	-0.22	-1.1	
164034.	281.	16.12	511.	109.	28.67	19.89	34.3	2.22	777.	582.6	096	216	7.2	0.91	0.83	0.80	0.14	1.8	0.19	44.	-22.0	213.	-0.31	-0.5	
164648.	343.	16.69	511.	102.	28.90	19.83	34.1	2.47	787.	582.9	262	215	6.4	0.86	0.80	0.77	0.14	1.8	0.22	49.	-22.8	258.	-0.21	-1.0	
165359.	274.	15.73	510.	99.	29.15	19.88	35.8	2.19	798.	582.4	095	216	7.0	0.81	0.80	0.75	0.15	1.5	0.18	29.	-16.3	175.	-0.18	-0.7	
17 0 4.	315.	15.48	507.	89.	29.43	19.85	36.0	2.23	807.	582.3	262	214	6.2	0.89	0.76	0.77	0.17	1.7	0.21	58.	-19.8	242.	-0.19	-1.1	
UPPER LEVEL RUN, 3100' MSL, TRACK-8																									
1710	1.	280.	16.19	961.	566.	25.62	18.82	35.2	1.95	839.	552.2	093	219	4.9	0.83	0.77	0.55	0.47	1.5	0.47	-37.	-2.9	110.	-0.02	79.1

TABLE 9(f): TWIN OTTER DATA - FIFE89 FLIGHT 06 - 04 AUGUST, 1989

FUSELAGE TEMPERATURE DATA USED; FILTERED AT 0.01200

RUN AVERAGES														RMS			CORRECTED FLUXES									
ST	GMT	SEC	DIST	PALT	RALT	TEMP	DEWPT	PRT5	GRN	RADUP	LICOR	HDGL	WINDLD	UGEL	VGEL	WEP	TS	CO2	H2O	WT	WC	WQ	WV	Z/L		
			km	m	m	degC	degC	degC	degC	W/m ²	mg/m ³	T	T	ms ⁻¹	ms ⁻¹	degC	mg/m ³	mg/m ³	gm/m ³	W/m ²	kg/hh	W/m ²	W/m ²	N/m ²		
8- LINE GRID, 1600' MSL WORKING NORTH TO SOUTH																										
1838	1.	291.	15.95	503.	139.	31.77	20.70	44.6	1.74	858.	581.2	095	200	6.3	0.83	1.01	0.96	0.18	1.1	0.20	115.	-8.8	220.	-0.25	-2.0	
1844	37.	302.	15.52	499.	101.	31.89	20.87	42.2	1.96	862.	579.3	261	193	5.8	0.78	0.97	0.88	0.16	1.3	0.24	91.	-11.5	278.	-0.25	-1.2	
1850	56.	278.	15.49	503.	104.	31.99	20.84	41.7	2.09	857.	577.7	095	193	6.5	0.79	1.06	0.83	0.16	1.3	0.26	82.	-13.6	277.	-0.24	-1.2	
1856	48.	284.	15.34	504.	95.	32.15	20.73	41.0	1.98	860.	577.1	261	189	5.7	0.81	0.90	0.80	0.14	1.9	0.34	72.	-21.5	371.	-0.19	-1.4	
19	3	6.	298.	16.16	502.	95.	32.31	20.71	40.0	2.22	853.	576.6	094	189	6.0	0.79	0.92	0.78	0.13	1.7	0.32	50.	-19.3	321.	-0.25	-0.7
19	931.	304.	16.34	503.	94.	32.37	20.79	39.0	2.38	852.	575.9	261	185	5.8	0.75	1.01	0.76	0.12	1.7	0.33	45.	-15.0	256.	-0.11	-2.0	
1916	6.	300.	16.48	504.	91.	32.45	21.03	40.5	2.22	845.	581.0	094	183	6.2	0.81	1.10	0.77	0.15	1.8	0.33	61.	-19.7	321.	-0.16	-1.6	
1922	53.	275.	15.14	505.	83.	32.40	21.20	39.6	2.17	843.	*	261	180	6.1	0.86	1.05	0.74	0.13	1.6	0.28	51.	-13.5	230.	-0.21	-0.8	
RUN NEAR TOP OF PBL AT 3100', TRACK-8, SOUTH EDGE AND ONE AT 2300 '																										
1930	28.	310.	17.27	958.	567.	27.93	19.78	39.2	1.96	849.	*	096	200	7.1	0.72	0.81	0.80	0.15	1.1	0.27	6.	-4.3	218.	-0.09	-5.5	
1938	19.	302.	16.14	718.	315.	30.15	20.84	39.3	2.02	838.	*	261	185	6.6	0.81	0.83	0.90	0.13	1.0	0.24	-3.	-7.8	230.	-0.06	-3.5	
8-LINE GRID, 1600' MSL, WORKING SOUTH TO NORTH																										
1946	29.	292.	15.55	510.	91.	32.49	21.44	40.9	2.12	818.	*	097	177	6.9	0.83	0.91	0.83	0.19	1.7	0.26	59.	-18.9	304.	-0.22	-0.9	
1953	30.	301.	16.39	510.	95.	32.55	21.55	39.2	2.18	810.	*	262	174	6.7	0.76	1.07	0.76	0.17	2.9	0.47	29.	-17.9	279.	-0.17	-0.9	
1959	43.	303.	16.21	508.	99.	32.66	21.62	39.3	2.42	798.	*	096	176	7.5	0.86	0.98	0.81	0.17	1.9	0.35	31.	-22.7	371.	-0.32	-0.4	
20	6	9.	295.	16.41	511.	105.	32.65	21.75	39.3	2.14	790.	*	260	171	7.4	0.90	0.92	0.79	0.15	1.7	0.33	20.	-15.6	265.	-0.18	-0.7
2012	29.	314.	16.38	510.	103.	32.72	21.71	40.8	2.02	779.	*	098	175	8.3	0.86	0.86	0.83	0.18	1.9	0.31	45.	-14.8	215.	-0.21	-0.9	
2019	10.	289.	16.13	511.	109.	32.65	21.99	41.0	2.01	771.	*	259	169	8.1	0.85	0.98	0.76	0.17	2.5	0.46	37.	-11.6	249.	-0.21	-0.8	
2025	41.	306.	15.98	509.	114.	32.80	21.84	41.8	2.05	758.	*	098	175	8.9	0.83	0.90	0.80	0.18	1.8	0.33	42.	-14.2	329.	-0.23	-0.9	
2032	26.	293.	16.44	512.	139.	32.67	22.09	42.7	1.78	746.	*	259	168	8.8	0.96	0.88	0.80	0.17	1.6	0.27	51.	-11.5	274.	-0.22	-1.3	
RUN NEAR TOP OF PBL, NORTH EDGE, 3400' MSL																										
2040	46.	288.	16.86	1062.	730.	28.20	19.16	41.5	1.63	749.	*	098	205	8.6	0.53	0.63	0.60	0.20	0.7	0.42	-15.	-0.1	136.	0.03	-8.6	
REGIONAL RUN C, 500' AGL (CO2/H2O GOES U/S)																										
2048	47.	658.	38.83	571.	159.	32.30	21.20	40.1	1.90	715.	*	233	179	8.7	0.94	0.92	0.92	0.13	1.5	0.29	62.	-12.0	271.	-0.30	-1.0	
2059	52.	710.	40.35	552.	158.	33.46	20.46	46.1	1.47	692.	*	232	184	9.3	0.85	1.09	0.94	0.17	*	*	101.	*	*	-0.17	-3.0	

TABLE 9(g): TWIN OTTER DATA - FIFE89 FLIGHT 07 - 04 AUGUST, 1989

FUSELAGE TEMPERATURE DATA USED; FILTERED AT 0.01200

RUN AVERAGES														RMS		CORRECTED FLUXES								
ST	GMT	SEC	DIST	PALT	RALT	TEMP	DEWPT	PRT5	GRN	RADUP	LICOR	HDGL	WINDLD	UGEL	VGEL	WEP	TS	CO2	H2O	WT	WC	WQ	WV	Z/L
			km	m	m	degC	degC	degC	W/m ²	mg/m ³	T	T	ms ⁻¹	ms ⁻¹	degC	mg/m ³	gm/m ³	gm/m ³	W/m ²	kg/hh	W/m ²	W/m ²	N/m ²	
L-PATTERN , EAST/WEST RUNS, FW5-FE5																								
300' BELOW PBL TOP																								
152827.	316.	15.71	624.	204.	19.53	13.50	25.7	2.27	632.	602.7	0.86	054	5.1	0.57	0.64	0.74	0.10	2.9	0.24	24.	19.6	216.	-0.11	-3.1
155758.	338.	16.74	653.	244.	19.75	13.10	26.9	2.25	699.	590.0	0.85	047	5.5	0.81	0.77	0.91	0.11	2.3	0.24	43.	7.7	307.	-0.27	-1.6
1626	4.	220.	10.91	660.	275.	20.14	12.93	29.2	1.89	757.	590.5	0.81	047	0.73	0.51	0.94	0.07	1.1	0.09	16.	-10.2	70.	-0.47	-0.2
163449.	287.	16.66	993.	587.	18.10	10.53	27.9	2.17	783.	558.9	0.75	037	6.1	0.77	0.68	0.46	0.63	3.8	0.88	-32.	-1.1	21.	0.00*****	
17	326.	288.	16.32	957.	552.	17.83	12.21	29.2	2.13	825.	562.7	0.74	035	0.65	0.79	0.62	0.26	1.5	0.47	-29.	3.9	132.	-0.09	5.5
175544.	305.	16.12	1084.	681.	17.49	11.44	31.8	2.04	879.	548.4	0.82	002	5.2	0.74	0.76	0.76	0.20	0.9	0.43	1.	-2.6	69.	0.001518.2	
1600'MSL																								
153624.	290.	16.42	501.	83.	20.85	13.75	25.5	2.48	645.	610.2	0.273	054	5.7	0.77	0.73	0.68	0.12	1.6	0.18	48.	-6.1	143.	-0.17	-1.0
16	520.	283.	16.41	506.	92.	21.42	13.37	27.4	2.43	709.	597.0	0.272	049	0.69	0.78	0.74	0.16	1.9	0.22	86.	-15.7	233.	-0.19	-1.6
165537.	327.	16.33	510.	98.	22.08	13.46	30.6	2.30	805.	595.3	0.86	046	4.1	0.75	0.91	0.84	0.20	2.2	0.23	129.	-27.5	308.	-0.11	-5.9
172513.	316.	16.23	508.	93.	22.60	13.47	31.9	2.28	838.	588.2	0.85	031	4.3	0.89	0.94	0.85	0.17	2.0	0.23	102.	-21.3	254.	-0.18	-2.1
173236.	299.	16.41	501.	87.	22.83	13.29	31.7	2.35	840.	587.6	0.274	028	5.1	0.81	0.86	0.88	0.17	1.8	0.22	108.	-25.8	278.	-0.18	-2.1
L-PATTERN , NORTH/SOUTH RUNS, FS3-FN3																								
300' BELOW PBL TOP																								
1551	7.	231.	13.24	652.	266.	19.63	13.19	28.0	1.81	687.	601.8	0.174	043	0.79	0.89	0.92	0.10	2.9	0.26	23.	34.7	304.	-0.26	-1.3
161921.	238.	13.60	659.	276.	20.10	12.86	29.9	1.76	744.	589.3	0.173	044	5.6	0.74	0.77	0.97	0.11	1.2	0.20	67.	-4.2	195.	-0.17	-4.5
164232.	267.	13.45	956.	574.	18.06	11.39	31.0	1.71	798.	563.7	0.002	043	5.1	0.81	0.71	0.68	0.46	2.9	0.75	-26.	2.5	90.	-0.08	6.6
171110.	282.	13.82	952.	572.	18.17	12.17	32.5	1.69	834.	562.2	0.000	032	4.5	0.75	0.79	0.93	0.15	1.0	0.32	-14.	1.2	191.	0.06	-0.2
174916.	208.	12.49	1077.	703.	17.83	11.08	34.1	1.60	870.	550.6	0.178	011	6.0	0.90	0.65	0.75	0.17	0.6	0.34	-26.	-1.6	230.	0.04	-12.6
1600' MSL																								
1545	4.	260.	13.02	505.	114.	20.97	13.51	27.6	1.91	669.	614.8	0.004	054	0.80	0.83	0.88	0.14	2.2	0.18	77.	-4.5	171.	-0.15	-2.5
1613	8.	260.	12.97	502.	114.	21.61	13.16	29.8	1.87	726.	602.6	0.004	052	0.93	0.81	0.82	0.17	1.9	0.21	101.	-10.0	191.	-0.14	-3.5
164853.	240.	13.60	514.	128.	22.02	13.23	32.6	1.81	797.	594.9	0.175	044	4.7	0.94	0.78	0.89	0.14	1.2	0.15	85.	-14.8	166.	-0.12	-3.9
1718	7.	252.	14.16	512.	125.	22.63	13.15	34.3	1.79	832.	591.0	0.176	032	1.00	0.87	0.93	0.19	1.1	0.20	140.	-14.5	182.	-0.21	-2.8
174119.	292.	13.58	499.	112.	23.27	12.75	35.1	1.82	842.	589.3	0.000	021	4.9	0.96	0.88	1.00	0.19	1.0	0.18	124.	-12.3	234.	-0.26	-1.7
**INTERCOMPS WITH KINGAIR																								
18	854.	235.	16.64	592.	182.	22.39	12.45	32.9	2.21	870.	579.4	0.274	014	0.76	0.97	1.00	0.13	1.6	0.20	84.	-25.4	295.	-0.25	-2.2
181620.	240.	16.52	507.	95.	23.48	12.66	33.8	2.27	865.	584.1	0.086	013	4.2	1.02	1.09	0.87	0.16	1.9	0.24	93.	-28.3	330.	-0.15	-2.7

TABLE 9(h): TWIN OTTER DATA - FIFE89 FLIGHT 08 - 06 AUGUST, 1989

FUSELAGE TEMPERATURE DATA USED; FILTERED AT 0.01200

RUN AVERAGES														RMS			CORRECTED FLUXES							
ST	GMT	SEC	DIST	PALT	RALT	TEMP	DEWPT	PRT5	GRN	RADUP	LICOR	HDGL	WINDLD	UGEL	VGEL	WEP	TS	CO2	H2O	WT	WC	WQ	UN	Z/L
			km	m	m	degC	degC	degC	W/m ²	W/m ²	mg/m ³	T	T	ms ⁻¹	ms ⁻¹	degC	mg/m ³	mg/m ³	gm/m ³	W/m ²	kg/hh	W/m ²	W/m ²	N/m ²
RUN NEAR TOP OF PBL, 4800', FE0-FW0																								
193820.	323.	17.17	1484.	*	14.39	10.59	31.0	1.70	826.	525.9	281	358	9.1	0.81	1.02	1.19	0.13	1.0	0.50	-10.	-5.7	165.	0.00	96.1
8-LINE GRID, 1600' MSL, WORKING NORTH TO SOUTH																								
1947 3.	310.	16.51	503.	135.	24.30	12.69	34.6	1.86	785.	588.8	079	354	9.4	1.15	1.38	1.14	0.24	1.2	0.12	184.	-14.9	226.	-0.65	-0.7
195332.	288.	15.28	507.	106.	24.40	12.72	31.5	2.13	767.	587.7	280	347	9.8	1.21	1.82	1.12	0.23	1.4	0.18	165.	-18.6	299.	-0.48	-0.8
195938.	296.	15.56	505.	98.	24.39	12.66	32.2	2.19	795.	587.7	080	358	8.6	1.20	1.34	0.98	0.19	1.3	0.19	120.	-15.8	273.	-0.53	-0.5
20 557.	309.	16.22	503.	88.	24.43	12.72	33.0	2.02	794.	586.7	278	359	8.7	1.10	1.19	0.88	0.19	1.3	0.19	111.	-15.9	245.	-0.27	-1.1
2013 4.	317.	16.73	504.	95.	24.32	12.61	31.7	2.36	778.	586.1	079	000	8.8	0.98	1.04	0.82	0.15	1.3	0.19	67.	-10.8	181.	-0.36	-0.5
2020 2.	309.	16.42	508.	92.	24.40	12.78	30.9	2.42	756.	584.1	279	000	9.7	0.99	1.07	0.89	0.16	1.6	0.21	90.	-19.7	265.	-0.36	-0.7
202636.	311.	16.20	507.	87.	24.44	12.84	31.8	2.32	730.	583.3	079	359	9.1	1.08	1.41	0.80	0.19	1.9	0.22	96.	-20.5	257.	-0.41	-0.5
2033 3.	284.	15.07	506.	78.	24.59	13.05	31.5	2.16	691.	582.3	278	004	9.2	1.47	1.27	0.94	0.20	2.0	0.24	107.	-24.7	288.	-0.48	-0.4
RUN 300' BELOW TOP OF PBL, FE6-FW6																								
204717.	298.	15.64	1760.	*	12.74	7.85	28.9	1.82	757.	508.7	283	355	10.6	0.65	0.71	0.43	0.23	0.9	0.39	-16.	1.7	-3.	-0.09	6.4
8-LINE GRID, 1600', WORKING SOUTH TO NORTH																								
205712.	296.	15.75	509.	83.	24.39	12.06	31.3	2.32	703.	582.8	079	004	9.4	1.38	1.18	0.95	0.19	1.8	0.22	103.	-20.1	257.	-0.34	-0.7
21 422.	305.	16.35	506.	85.	24.21	11.77	30.1	2.24	686.	583.3	280	003	9.8	1.22	1.33	0.86	0.16	1.8	0.22	77.	-18.4	225.	-0.50	-0.3
211124.	334.	17.05	505.	91.	24.12	11.25	29.4	2.57	663.	584.4	078	001	9.8	1.13	1.19	0.87	0.14	1.5	0.20	74.	-16.6	227.	-0.30	-0.7
211838.	468.	24.67	506.	79.	24.02	11.34	28.7	2.36	657.	583.5	280	007	10.2	1.13	1.20	0.85	0.13	1.6	0.21	61.	-17.8	236.	-0.37	-0.4
212819.	337.	16.66	508.	90.	23.94	11.39	30.8	2.15	621.	582.4	081	018	7.8	1.17	1.23	0.88	0.16	1.2	0.16	92.	-11.7	194.	-0.47	-0.4
213557.	295.	16.19	505.	92.	23.90	11.43	29.3	2.17	606.	581.9	278	014	8.3	1.01	1.11	0.87	0.13	1.0	0.12	67.	-9.9	141.	-0.36	-0.5
214227.	317.	15.55	503.	99.	23.93	11.51	29.4	2.23	588.	581.5	081	020	7.3	1.04	1.32	0.91	0.17	1.2	0.14	108.	-13.4	191.	-0.46	-0.5
214911.	295.	16.18	502.	124.	23.93	11.30	29.7	1.95	570.	582.2	277	024	7.6	1.00	1.05	1.03	0.16	1.0	0.11	100.	-12.5	180.	-0.40	-0.8
RUN 200' BELOW TOP OF PBL, 4800'MSL																								
215925.	301.	16.05	1488.	*	14.61	8.60	28.8	1.71	567.	523.0	079	000	8.2	1.21	0.99	0.70	0.38	1.4	0.38	56.	2.6	-73.	0.06	35.0
REGIONAL C, 500' AGL																								
22 714.	556.	37.92	570.	150.	23.48	11.42	28.6	2.10	519.	577.8	244	025	7.8	1.00	1.05	0.88	0.11	1.0	0.13	53.	-10.9	143.	-0.34	-0.7
221636.	594.	40.38	555.	151.	24.31	11.40	32.5	1.51	479.	580.0	242	034	7.6	1.04	0.99	0.92	0.13	0.9	0.11	71.	-8.2	123.	-0.29	-1.1

TABLE 9(i): TWIN OTTER DATA - FIFE89 FLIGHT 09 - 06 AUGUST, 1989

RUN AVERAGES														RMS		CORRECTED FLUXES								
ST	GMT	SEC	DIST	PALT	RALT	TEMP	DEWPT	PRT5	GRN	RADUP	LICOR	HDGL	WINDLD	UGEL	VGEL	WEP	TS	CO2	H2O	WT	WC	WQ	WU	Z/L
			km	m	m	degC	degC	degC	degC	W/m ²	mg/m ³	T	T	ms ⁻¹	ms ⁻¹	degC	mg/m ³	gm/m ³	gm/m ³	W/m ²	kg/hh	W/m ²	W/m ²	W/m ²
T-PATTERN FLIGHT																								
EAST/WEST FW5-FE5																								
155136.	291.	16.19	501.	77.	16.42	4.42	24.2	2.56	729.	590.3	275	026	6.7	1.09	1.28	0.93	0.19	1.6	0.16	136.	-24.1	198.	-0.47	-0.5
155824.	335.	16.32	596.	174.	15.45	4.30	25.3	2.43	752.	583.8	083	026	6.4	1.04	1.12	0.93	0.14	1.3	0.12	88.	-15.2	144.	-0.07	-14.8
16 616.	304.	16.29	891.	467.	12.52	3.58	24.6	2.41	769.	564.3	276	023	7.2	0.98	0.87	1.03	0.11	1.2	0.10	47.	-11.7	136.	0.01	344.8
161549.	341.	17.33	1756.	1332.	4.44	1.77	24.5	2.13	833.	511.2	080	013	7.0	1.01	1.02	0.71	0.17	0.8	0.19	-20.	-1.0	56.	-0.19	2.2
173532.	308.	16.89	1762.	1334.	5.21	2.31	28.8	2.07	962.	510.0	277	*	*	0.82	0.88	0.97	0.14	0.9	0.13	-4.	-7.5	106.	-0.02	-8.9
174424.	334.	17.36	906.	479.	13.74	4.01	31.0	2.21	931.	562.4	082	017	6.2	1.34	1.01	1.26	0.11	1.0	0.09	73.	-10.3	136.	-0.13	-11.6
175252.	303.	16.52	600.	173.	16.96	4.53	31.1	2.31	1022.	582.3	275	020	6.3	1.05	1.05	1.24	0.15	1.3	0.13	137.	-21.1	221.	-0.11	-10.4
18 0 9.	333.	16.42	513.	84.	18.05	4.73	31.4	2.37	936.	587.0	084	022	5.1	1.07	1.39	1.00	0.24	1.8	0.20	188.	-28.0	299.	-0.32	-1.4
NORTH/SOUTH FS2-FN2																								
163025.	371.	17.74	1762.	1341.	4.36	2.42	25.5	2.05	838.	512.2	003	017	6.2	1.07	0.86	0.89	0.11	0.9	0.13	-6.	-5.9	86.	-0.05	-0.1
163929.	288.	16.60	900.	479.	12.96	3.65	26.5	2.19	822.	568.6	179	017	6.9	0.94	0.91	1.16	0.10	1.4	0.06	65.	-11.7	100.	-0.01	*****
164656.	366.	16.46	595.	174.	16.09	4.16	27.6	2.31	861.	588.4	004	025	6.4	1.01	1.09	1.00	0.13	1.2	0.11	88.	-15.6	147.	0.08	10.0
165444.	280.	16.29	522.	102.	16.95	4.32	28.1	2.29	876.	591.9	179	018	6.0	1.23	0.96	0.96	0.21	1.4	0.16	147.	-20.6	214.	0.01	493.9
17 124.	347.	16.33	522.	101.	17.07	4.35	28.2	2.35	874.	590.5	003	003	5.3	1.17	1.08	1.00	0.19	1.6	0.15	145.	-20.8	218.	-0.07	-12.7
17 850.	281.	15.97	603.	183.	16.34	4.17	28.5	2.26	895.	583.7	179	018	6.1	1.11	1.21	1.01	0.15	1.2	0.10	102.	-14.7	145.	-0.37	-1.3
171547.	353.	16.46	903.	479.	13.36	3.78	28.8	2.20	897.	562.7	004	023	6.2	0.98	1.10	1.32	0.10	1.0	0.08	65.	-8.0	106.	-0.09	-20.0
172540.	271.	16.38	1763.	1341.	5.14	2.24	27.8	2.00	926.	508.5	179	006	6.6	1.09	0.93	0.85	0.12	1.0	0.16	-2.	-1.6	35.	-0.11	-0.2
REGIONAL RUN C, 500 AGL **PASS KINGAIR IN SEGMENT 1																								
181649.	582.	38.71	581.	156.	17.56	4.54	32.4	2.07	943.	582.7	244	015	5.7	1.18	1.22	1.21	0.21	1.3	0.13	201.	-21.6	266.	-0.37	-2.2
182638.	606.	39.79	556.	151.	18.19	4.28	37.9	1.57	941.	583.6	244	013	5.4	1.24	1.34	1.31	0.19	1.1	0.11	199.	-11.8	157.	-0.03	-101.7

TABLE 9(j): TWIN OTTER DATA - FIFE89 FLIGHT 10 - 07 AUGUST, 1989

FUSELAGE TEMPERATURE DATA USED; FILTERED AT 0.01200

RUN AVERAGES														RMS			CORRECTED FLUXES							
ST	GMT	SEC	DIST	PALT	RALT	TEMP	DEWPT	PRTS	GRN	RADUP	LICOR	HDGL	WINDLD	UGEL	VGEL	WEP	TS	C02	H2O	WT	WC	WQ	UW	Z/L
			km	m	m	degC	degC	degC	degC	W/m ²	mg/m ³	T	T	ms ⁻¹	ms ⁻¹	degC	mg/m ³	degC	gm/m ³	W/m ²	kg/hh	W/m ²	N/m ²	
REGIONAL RUN C, 500'																								
152428.	660.	39.89	548.	160.	19.01	7.35	30.0	1.62	650.	580.9	058	349	2.1	0.68	0.65	0.88	0.12	2.0	0.17	71.	10.2	190.	-0.17	-2.6
153534.	643.	38.98	563.	159.	19.33	7.24	27.0	2.19	683.	575.0	057	343	3.0	0.71	0.79	0.94	0.13	2.0	0.23	85.	-10.3	210.	-0.11	-6.2
UPPER RUNS NEAR PBL TOP																								
NORTH EDGE																								
155351.	339.	17.38	894.	533.	16.30	6.81	28.0	1.98	723.	552.3	272	328	3.2	0.75	0.88	0.90	0.07	3.0	0.27	6.	21.9	220.	-0.24	-1.4
181756.	258.	15.47	2167.	*	5.69	2.99	31.8	1.63	853.	470.7	088	314	1.9	0.96	0.82	1.11	0.11	1.1	0.23	-14.	-10.1	240.	-0.02	-11.9
SOUTH EDGE																								
17 8 6.	342.	19.47	2006.	*	6.33	3.45	30.8	1.98	809.	482.0	272	358	2.2	0.80	0.91	0.80	0.11	1.4	0.26	1.	-11.7	199.	0.04	17.8
GRID, 1600' MSL WORKING NORTH TO SOUTH																								
16 143.	295.	16.38	501.	135.	20.36	7.98	31.1	1.89	731.	581.2	087	319	2.6	0.92	0.92	0.95	0.18	2.5	0.16	128.	-13.5	151.	-0.15	-4.8
16 8 3.	300.	15.52	505.	106.	20.50	7.77	29.3	2.26	742.	579.1	272	326	3.3	0.85	0.95	0.92	0.16	1.7	0.16	110.	-18.0	193.	0.02	94.2
161448.	292.	16.06	502.	103.	20.60	7.88	29.6	2.24	757.	579.1	087	312	2.9	0.87	0.98	0.96	0.16	1.5	0.17	119.	-10.5	221.	-0.05	-19.7
162122.	305.	15.63	502.	94.	20.73	7.51	30.9	2.24	767.	576.9	271	325	3.3	0.91	0.94	0.89	0.16	1.6	0.21	119.	-14.0	277.	-0.16	-2.9
162810.	298.	16.13	506.	102.	20.86	7.43	30.4	2.32	786.	575.9	087	316	2.8	0.98	0.91	0.97	0.17	1.8	0.23	137.	-23.9	318.	-0.14	-4.3
163454.	331.	16.50	501.	91.	21.00	7.23	29.4	2.60	767.	573.0	271	317	2.5	0.86	1.01	0.83	0.15	1.6	0.20	76.	-16.3	180.	0.02	34.1
1642 9.	293.	15.94	502.	87.	21.08	7.15	31.3	2.37	786.	573.1	088	305	2.5	0.84	1.00	0.88	0.17	1.7	0.20	118.	-25.1	231.	-0.12	-3.7
164841.	311.	15.85	501.	80.	21.18	6.71	31.9	2.30	815.	572.7	270	313	2.4	0.88	1.06	0.90	0.19	1.6	0.20	130.	-21.2	245.	-0.06	-10.3
GRID, 1600' MSL WORKING SOUTH TO NORTH																								
171916.	288.	15.78	511.	88.	21.44	6.25	32.4	2.29	792.	575.6	089	296	1.7	1.08	0.97	0.91	0.16	1.5	0.19	87.	-16.9	163.	-0.08	-5.1
172537.	311.	16.32	507.	88.	21.55	6.41	32.7	2.33	845.	576.3	270	318	1.4	1.12	1.07	0.94	0.15	1.4	0.17	83.	-16.6	187.	-0.06	-8.5
173244.	305.	16.48	509.	97.	21.57	6.51	31.7	2.51	797.	575.2	087	315	1.8	0.97	1.07	0.80	0.15	1.6	0.19	89.	-18.5	170.	-0.05	-12.6
173932.	312.	16.17	510.	98.	21.69	6.45	32.7	2.33	841.	574.1	269	301	1.2	0.98	1.06	0.99	0.16	1.4	0.17	110.	-23.0	250.	-0.05	-16.9
174635.	296.	16.34	512.	100.	21.78	6.59	33.7	2.01	730.	572.0	087	307	2.6	0.90	1.03	0.85	0.15	1.4	0.14	84.	-14.9	168.	0.06	10.1
175319.	311.	16.32	510.	103.	21.93	6.61	33.5	2.19	841.	570.9	270	310	1.9	1.13	0.97	1.08	0.20	1.4	0.15	150.	-18.4	212.	-0.08	-10.6
18 011.	285.	15.63	513.	115.	21.95	6.26	33.0	2.18	808.	569.6	088	285	1.9	0.87	1.03	1.05	0.18	1.1	0.13	122.	-13.6	166.	0.03	50.6
18 633.	316.	16.17	508.	137.	22.12	6.34	34.5	1.91	758.	570.3	269	293	2.3	1.06	1.09	1.23	0.18	1.0	0.11	166.	-9.5	131.	-0.06	-24.1

TABLE 9(k): TWIN OTTER DATA - FIFE89 FLIGHT 11 - 08 AUGUST, 1989

FUSELAGE TEMPERATURE DATA USED; FILTERED AT 0.01200
MEAN WIND DIRECTION AND SPEED FROM LITTON

RUN AVERAGES														RMS			CORRECTED FLUXES									
ST	GMT	SEC	DIST	PALT	RALT	TEMP	DEWPT	PRT5	GRN	RADUP	LICOR	HDGL	WIND	UGEL	VGEL	WEP	TS	C02	H2O	WT	WC	WQ	UM	Z/L		
			km	m	m	degC	degC	degC	degC	W/m ²	mg/m ³	T	T	ms ⁻¹	ms ⁻¹	ms ⁻¹	degC	mg/m ³	gm/m ³	W/m ²	kg/hh	W/m ²	W/m ²	N/m ²		
UPPER LEVEL RUNS																										
NORTH EDGE																										
195114.	376.	20.04	2303.	*	5.24	2.29	32.4	1.75	871.	467.2	273	342	3.5	1.00	0.85	0.76	0.11	0.7	0.22	-11.	0.9	10.	-0.09	4.2		
212814.	250.	14.58	2322.	*	5.89	1.66	30.2	1.86	684.	465.1	087	003	3.2	0.89	1.01	1.10	0.14	1.0	0.26	2.	-1.6	51.	-0.09	-2.2		
SOUTH EDGE																										
204019.	416.	22.03	2304.	*	5.73	0.71	31.4	1.92	817.	467.8	271	303	4.6	0.87	0.67	0.67	0.11	1.1	0.36	1.	1.5	-26.	0.00	-36.2		
MINI GRID, TRACKS 2,4,6,8 -- 1600' MSL																										
20	129.	286.	15.54	501.	101.	23.41	5.76	37.8	2.19	873.	576.1	089	303	1.1	0.92	1.13	1.08	0.20	1.4	0.15	175.	-20.7	212.	-0.06	-17.9	
20	815.	314.	16.17	500.	87.	23.39	5.53	35.5	2.07	789.	576.9	270	329	2.1	0.85	1.24	0.86	0.15	1.3	0.17	86.	-11.0	150.	-0.04	-14.0	
201560.	308.	16.42	503.	90.	23.51	4.58	33.8	2.62	815.	578.0	088	354	2.1	1.00	1.21	0.96	0.14	1.7	0.31	81.	-16.7	181.	-0.02	-35.9		
2024	0.	304.	15.93	504.	78.	23.54	5.31	33.9	2.29	809.	575.9	269	325	1.9	0.93	1.12	0.90	0.17	1.6	0.23	111.	-18.7	232.	-0.09	-5.0	
MINI GRID, TRACKS 8,6,4, AND 2, - 1600' MSL																										
2054	6.	290.	15.66	502.	74.	23.89	4.62	34.2	2.41	747.	578.1	087	341	1.7	1.05	1.05	0.86	0.15	1.8	0.32	93.	-16.0	209.	-0.11	-3.1	
21	1	0.	301.	15.94	503.	87.	23.89	5.05	32.2	2.48	701.	576.9	271	337	1.9	0.96	1.07	0.90	0.25	1.4	0.22	98.	-16.8	204.	-0.12	-3.2
21	835.	308.	16.65	504.	95.	23.99	5.24	34.8	2.23	697.	575.8	086	000	2.3	0.90	1.02	1.09	0.15	1.3	0.19	106.	-17.0	226.	-0.15	-2.8	
2116	9.	302.	15.57	503.	96.	24.01	5.08	31.7	2.28	665.	575.7	269	292	0.4	0.95	1.10	0.90	0.12	1.1	0.16	76.	-12.7	167.	0.01	87.4	
REGIONAL RUN C, 500' AGL																										
213629.	626.	38.98	574.	156.	23.43	5.10	31.9	2.16	594.	572.9	240	003	1.5	0.96	1.05	1.10	0.12	1.0	0.15	68.	-12.4	186.	0.07	10.4		
2147	2.	617.	39.84	560.	159.	24.29	4.05	37.5	1.58	593.	577.1	240	349	1.1	1.03	1.26	1.11	0.15	0.9	0.09	114.	-7.6	100.	0.02	81.9	

TABLE 9(I): TWIN OTTER DATA - FIFE89 FLIGHT 12 - 08 AUGUST, 1989

FUSELAGE TEMPERATURE DATA USED; FILTERED AT 0.01200
MEAN WIND DIRECTION AND SPEED FROM LITTON

RUN AVERAGES														RMS			CORRECTED FLUXES									
ST	GMT	SEC	DIST	PALT	RALT	TEMP	DEWPT	PRT5	GRN	RADUP	LICOR	HDGL	WIND	UGEL	VGEL	WEP	TS	CO2	H2O	WT	WC	WQ	WZ	Z/L		
			km	m	m	degC	degC	degC	degC	W/m ²	W/m ²	T	T	ms ⁻¹	ms ⁻¹	degC	degC	mg/m ³	gm/m ³	W/m ²	kg/hh	W/m ²	W/m ²	N/m ²		
REGIONAL RUN C, 500' AGL																										
16	08	32	571	40.42	547.	159.	21.79	10.20	31.2	1.49	641.	567.7	066	195	11.2	1.21	1.08	0.97	0.16	1.0	0.13	109.	-8.3	164.	-0.53	-0.7
16	18	08	549	38.52	564.	164.	22.15	10.23	31.3	1.99	722.	562.7	065	197	9.5	1.09	1.09	1.03	0.15	1.3	0.15	101.	-14.3	148.	-0.32	-1.4
PBL RUNS - NORTH EDGE THEN SOUTH EDGE																										
16	36	40	332	17.36	1755.	*	10.69	7.56	30.8	1.58	811.	489.4	261	194	8.6	0.73	0.81	0.89	0.16	0.7	0.24	-15.	-3.2	217.	0.03	-0.5
17	47	17	316	16.86	1855.	*	10.11	7.30	30.1	1.74	658.	480.6	260	194	8.4	0.69	0.74	0.80	0.11	1.0	0.17	-11.	-6.8	109.	0.02	-19.1
GRID, 1600', WORKING NORTH TO SOUTH																										
16	46	01	296	16.05	496.	132.	23.37	10.65	34.6	1.83	832.	568.3	097	187	8.4	1.09	1.15	1.19	0.23	1.3	0.15	204.	-18.7	173.	-0.34	-2.0
16	52	47	312	15.49	499.	106.	23.39	10.66	32.3	2.14	764.	567.2	259	189	9.1	1.21	1.11	1.04	0.19	1.3	0.13	131.	-15.8	157.	-0.52	-0.6
16	59	52	285	15.37	504.	107.	23.47	10.63	34.0	2.09	808.	565.2	098	185	8.1	1.09	1.22	1.07	0.21	1.3	0.13	146.	-15.0	167.	-0.45	-0.8
17	06	30	324	16.14	507.	101.	23.42	10.49	32.0	2.02	666.	564.0	258	191	9.2	1.09	1.22	0.93	0.19	1.6	0.16	125.	-22.2	205.	-0.48	-0.6
17	13	16	297	16.04	508.	105.	23.52	10.52	33.0	2.20	805.	562.9	098	192	8.6	1.12	1.47	0.98	0.22	1.8	0.17	161.	-27.7	263.	-0.44	-0.9
17	20	14	326	16.25	506.	98.	23.44	10.42	31.8	2.35	714.	562.6	259	194	9.1	1.05	1.30	0.93	0.19	1.5	0.14	119.	-17.0	174.	-0.39	-0.7
17	27	21	301	16.40	507.	96.	23.50	10.39	32.7	2.22	742.	562.5	098	196	8.6	1.12	1.38	0.92	0.19	1.7	0.16	113.	-22.3	211.	-0.38	-0.7
17	34	12	318	16.01	509.	91.	23.52	10.45	31.5	2.15	680.	561.2	259	195	9.4	1.19	1.16	1.14	0.19	1.5	0.13	142.	-23.2	199.	-0.31	-1.1
GRID, 1600', WORKING SOUTH TO NORTH																										
17	57	31	295	15.72	512.	92.	23.65	10.27	31.8	2.12	640.	564.0	097	182	7.6	1.13	1.25	1.04	0.19	1.2	0.10	134.	-17.1	156.	-0.39	-0.8
18	04	25	311	16.24	509.	95.	23.76	10.38	31.5	2.15	595.	563.8	260	180	8.4	1.22	1.25	1.13	0.19	1.4	0.14	153.	-24.6	225.	-0.38	-1.0
18	11	50	319	17.12	506.	99.	23.88	10.42	32.0	2.31	619.	563.1	097	174	7.6	1.06	1.39	0.98	0.18	1.6	0.15	130.	-23.5	206.	-0.26	-1.5
18	18	38	310	16.16	506.	100.	23.91	10.43	33.2	2.11	725.	562.5	259	172	8.6	1.04	1.29	1.08	0.19	1.6	0.16	135.	-24.7	233.	-0.27	-1.5
18	25	36	314	16.68	506.	99.	23.98	10.41	35.3	1.96	741.	561.9	097	171	7.7	0.99	1.38	0.92	0.17	1.5	0.16	97.	-20.2	193.	-0.29	-1.0

TABLE (m): TWIN OTTER DATA - FIFE89 FLIGHT 13 - 10 AUGUST, 1989

NAE C-FPOK , FILE 1ARCFFIFE89 (10 AUG 89), FLIGHT DAT 10-AUG-89 PRINT DATE 10-AUG-89 FIFE 89-14, NIGHT FLIGHT

FUSELAGE TEMPERATURE DATA USED; FILTERED AT 0.01200
MEAN WIND DIRECTION AND SPEED FROM LITTON

RUN AVERAGES														RMS			CORRECTED FLUXES									
ST	GMT	SEC	DIST	PALT	RALT	TEMP	DEWPT	PRT5	GRN	RADUP	LICOR	HDGL	WIND	UGEL	VGEL	WEP	TS	C02	H2O	WT	WC	WQ	UW	Z/L		
			km	m	m	degC	degC	degC	degC	W/m ²	mg/m ³	T	T	ms ⁻¹	ms ⁻¹		degC	mg/m ³	gm/m ³	W/m ²	kg/hh	W/m ²	N/m ²			
NIGHT RUNS, VERMA LINE, FW2-FE2																										
01	18	21	286	15.69	565.	155.	22.34	10.28	17.2	-3.07	1.	559.8	100	183	7.9	0.23	0.13	0.11	0.06	0.5	0.07	-1.	-0.1	2.	-0.01	2.7
01	32	23	302	16.03	506.	95.	22.60	10.58	16.5	-5.61	-11.	562.9	098	179	8.1	0.28	0.17	0.12	0.07	0.5	0.06	-1.	0.2	5.	-0.01	1.2
01	46	36	304	16.23	507.	98.	22.54	10.52	15.7	-7.00	-16.	561.0	098	178	8.3	0.22	0.14	0.10	0.05	0.5	0.04	-1.	0.2	3.	-0.01	2.5
02	01	06	296	15.75	502.	93.	22.48	10.55	15.7	-7.21	-17.	560.3	098	182	7.8	0.21	0.13	0.10	0.07	0.5	0.04	0.	0.1	2.	0.00	1.6
02	15	17	298	16.06	504.	99.	22.41	10.47	15.4	-7.28	-18.	559.5	098	188	7.1	0.18	0.10	0.09	0.06	0.4	0.04	-2.	0.1	1.	0.00	23.2
02	30	08	311	16.52	503.	101.	22.37	10.37	14.9	-7.21	-19.	559.8	097	189	6.6	0.21	0.12	0.10	0.06	0.4	0.06	-1.	0.0	3.	0.00	12.5
LINE FW4-FNE																										
01	25	17	303	15.61	564.	166.	22.37	10.30	17.1	-4.54	-8.	559.2	258	184	9.4	0.16	0.14	0.09	0.04	0.4	0.04	0.	0.1	1.	0.00	2.7
01	39	29	298	15.48	505.	104.	22.63	10.57	16.3	-6.24	-14.	561.9	259	182	9.1	0.21	0.15	0.14	0.05	0.5	0.05	0.	-0.1	2.	0.00	1.7
01	54	01	309	15.93	506.	108.	22.54	10.53	15.7	-7.22	-16.	560.5	260	184	8.9	0.21	0.14	0.11	0.06	0.6	0.10	-1.	0.1	3.	-0.01	3.3
02	08	09	311	16.05	501.	104.	22.47	10.54	15.6	-7.30	-17.	559.8	259	188	8.3	0.22	0.17	0.11	0.08	0.6	0.06	-2.	0.3	6.	-0.01	4.1
02	22	25	314	16.05	502.	109.	22.47	10.40	15.0	-7.22	-18.	559.3	259	192	7.6	0.16	0.13	0.10	0.07	0.5	0.06	0.	0.2	0.	0.00	2.5
02	37	17	307	15.63	502.	109.	22.47	10.24	15.0	-7.17	-19.	559.5	258	190	8.2	0.15	0.16	0.10	0.07	0.5	0.07	0.	0.2	0.	0.00	-8.6

TABLE 9(n): TWIN OTTER DATA - FIFE89 FLIGHT 14 - 10 AUGUST, 1989

FUSELAGE TEMPERATURE DATA USED; FILTERED AT 0.01200
MEAN WIND DIRECTION AND SPEED FROM LITTON

RUN AVERAGES														RMS			CORRECTED FLUXES									
ST	GMT	SEC	DIST	PALT	RALT	TEMP	DEWPT	PRT5	GRN	RADUP	LICOR	HDGL	WIND	UGEL	VGEL	WEP	TS	CO2	H2O	WT	WC	WQ	UM	Z/L		
			km	m	m	degC	degC	degC	degC	W/m ²	mg/m ³	T	T	ms ⁻¹	ms ⁻¹	degC	mg/m ³	mg/m ³	gm/m ³	W/m ²	kg/hh	W/m ²	W/m ²	N/m ²		
REGIONAL RUN C, 500 ' AGL (FORMATION WITH KINGAIR)																										
16	36	13	602	40.54	559.	169.	21.39	11.69	31.3	1.40	490.	565.3	064	181	6.7	0.95	1.04	1.02	0.16	1.1	0.15	103.	-11.7	171.	-0.35	-1.3
16	46	18	577	38.66	565.	162.	21.64	11.56	28.4	1.94	510.	560.7	066	176	6.6	0.89	0.96	0.93	0.12	1.2	0.21	71.	-15.4	210.	-0.29	-1.3
T-PATTERN, EAST/WEST PROFILE STACK, FFW-FNE																										
17	09	57	297	15.50	506.	111.	22.51	10.82	31.7	2.04	685.	563.0	261	173	8.0	0.95	1.01	0.97	0.22	1.2	0.13	150.	-13.8	139.	-0.42	-0.9
17	16	54	298	15.28	592.	201.	21.65	10.60	32.9	1.91	728.	557.1	098	170	7.6	0.96	0.90	1.16	0.18	1.2	0.17	159.	-13.3	266.	-0.32	-2.8
17	24	30	298	15.69	839.	449.	19.20	10.07	32.3	1.83	733.	540.5	261	176	8.0	0.92	0.83	1.30	0.13	1.2	0.20	114.	-5.7	362.	-0.42	-3.2
17	33	26	318	17.28	1481.	1089.	13.08	8.15	32.5	1.56	847.	501.8	098	178	7.4	0.63	0.74	0.76	0.17	1.0	0.46	-24.	-5.6	311.	0.01	-27.2
18	52	29	310	17.58	1543.	1145.	13.20	7.93	33.0	1.59	708.	498.3	262	170	6.6	0.90	0.81	1.10	0.14	2.0	0.44	-11.	-16.3	264.	-0.09	-3.3
19	01	17	318	15.88	865.	474.	20.03	9.52	34.9	1.77	717.	539.1	097	170	6.3	0.92	0.89	1.25	0.14	1.5	0.16	115.	-18.1	89.	-0.13	-16.7
19	08	47	294	15.58	597.	196.	22.88	9.82	34.3	1.93	738.	554.5	261	173	7.1	0.86	1.02	1.14	0.19	1.2	0.18	147.	-19.0	172.	-0.28	-2.9
19	15	29	295	15.42	509.	108.	23.84	10.27	35.6	1.96	721.	558.8	095	168	5.2	0.91	1.26	0.95	0.20	1.2	0.18	135.	-14.4	134.	-0.19	-2.7
T-PATTERN, NORTH/SOUTH , FN2-FS2																										
17	44	22	383	17.23	1536.	1126.	12.68	7.41	30.1	1.64	773.	500.1	181	173	8.4	0.53	0.65	0.50	0.14	0.7	0.44	-7.	-1.4	-3.	-0.04	10.2
17	53	07	278	16.49	865.	460.	19.27	9.38	33.3	1.91	848.	541.6	003	177	7.7	0.71	0.74	0.90	0.12	1.1	0.22	30.	-4.0	66.	-0.07	-11.5
18	00	41	371	16.89	599.	190.	22.10	10.06	34.7	2.00	864.	557.9	181	177	7.9	0.85	1.04	1.03	0.16	1.2	0.16	100.	-14.8	138.	-0.17	-4.1
18	08	43	274	16.75	520.	104.	23.05	10.34	34.7	2.12	839.	562.3	001	181	7.1	0.94	1.05	0.93	0.19	1.6	0.16	129.	-20.2	146.	-0.16	-3.0
18	15	53	363	16.52	523.	108.	23.07	10.29	35.0	2.04	857.	560.9	181	171	7.9	1.04	0.96	0.88	0.18	1.4	0.17	122.	-18.2	166.	-0.13	-4.5
18	23	53	280	16.63	590.	178.	22.36	10.16	34.7	2.04	800.	555.8	003	179	7.5	0.92	0.88	1.14	0.15	1.3	0.19	115.	-18.6	125.	-0.40	-1.2
18	30	53	368	16.51	869.	463.	19.61	9.73	34.0	1.87	776.	536.8	181	171	7.2	0.96	0.89	1.03	0.11	1.1	0.17	59.	-9.4	104.	-0.10	-13.5
18	39	56	263	16.71	1549.	1138.	12.90	8.35	32.1	1.67	782.	495.8	003	176	6.5	0.90	0.85	1.39	0.13	1.6	0.44	13.	-19.7	434.	-0.18	-6.3
REGIONAL RUN ON RETURN, FRE-FRW2																										
19	35	39	618	38.18	574.	159.	23.33	10.09	35.6	1.89	725.	553.4	235	174	6.2	1.05	1.16	0.99	0.14	1.4	0.22	90.	-15.4	159.	-0.20	-2.5
19	46	03	653	40.76	554.	154.	23.96	9.66	39.9	1.43	762.	558.0	234	177	7.3	1.10	1.35	1.35	0.23	1.2	0.11	213.	-14.5	125.	-0.12	-11.6

TABLE 9(o): TWIN OTTER DATA - FIFE89 FLIGHT 15 - 11 AUGUST, 1989

FUSELAGE TEMPERATURE DATA USED; FILTERED AT 0.01200; MEAN WIND DIRECTION AND SPEED FROM LITTON

RUN AVERAGES														RMS			CORRECTED FLUXES									
ST	GMT	SEC	DIST	PALT	RALT	TEMP	DEWPT	PRT5	GRN	RADUP	LICOR	HDGL	WIND	UGEL	VGEL	WEP	TS	CO2	H2O	WT	WC	WQ	UW	Z/L		
			km	m	m	degC	degC	degC	W/m ²	W/m ²	mg/m ³	T	T	ms ⁻¹	ms ⁻¹	ms ⁻¹	degC	mg/m ³	gm/m ³	W/m ²	kg/hh	W/m ²	W/m ²	N/m ²		
REGIONAL RUN, 500 ALG, ** INTERCOMP WITH KING AIR																										
16	10	09	606	40.59	548.	161.	22.74	11.14	33.7	1.45	626.	561.1	064	178	5.7	0.92	1.03	1.07	0.18	1.1	0.12	150.	-14.3	148.	-0.29	-2.3
16	20	19	583	38.49	540.	139.	22.81	10.82	32.5	*	684.	561.1	064	178	5.2	0.82	1.14	0.95	0.17	1.4	0.14	101.	-17.4	170.	-0.23	-2.0
UPPER PBL RUNS, NORTH EDGE																										
16	43	02	299	16.42	1333.	*	15.08	7.44	33.2	1.42	743.	515.2	262	177	6.7	0.61	0.73	0.80	0.13	2.1	0.62	-23.	-15.7	322.	-0.06	0.2
19	02	42	291	16.78	1948.	*	10.85	5.26	36.5	1.36	871.	478.3	096	202	4.8	0.68	0.74	0.60	0.18	2.1	0.57	-12.	-2.8	83.	-0.07	3.8
UPPER PBL RUNS, SOUTH EDGE																										
17	53	14	328	17.69	1846.	*	11.09	5.71	33.8	1.60	873.	486.1	264	187	5.5	0.95	0.85	0.86	0.27	2.4	0.97	3.	6.2-150.	0.02	-23.0	
8-LINE GRID, 1600 MSL, WORKING NORTH TO SOUTH																										
16	50	56	293	14.21	504.	143.	23.51	9.49	33.9	1.80	666.	566.5	098	175	5.5	0.76	1.12	1.04	0.16	1.4	0.13	142.	-17.0	162.	-0.32	-1.7
16	57	34	292	15.52	508.	113.	23.57	9.41	32.3	2.08	655.	566.3	263	176	6.0	0.83	1.18	0.96	0.18	1.4	0.17	132.	-19.4	221.	-0.21	-2.4
17	03	59	310	16.23	508.	112.	23.72	9.59	35.9	2.00	761.	566.0	095	169	4.6	0.97	1.15	0.93	0.20	1.8	0.14	120.	-16.5	177.	-0.29	-1.3
17	10	41	311	16.69	505.	98.	23.87	9.54	36.2	1.95	769.	565.5	263	180	5.3	0.92	1.23	1.04	0.19	1.5	0.17	139.	-20.7	176.	-0.05	-19.4
17	17	55	316	16.70	506.	103.	23.96	9.42	35.4	2.10	769.	565.9	095	184	5.1	0.84	1.26	1.02	0.19	1.7	0.22	120.	-22.9	210.	-0.17	-2.9
17	24	45	308	16.46	506.	96.	23.99	9.67	34.9	2.24	770.	565.7	263	183	5.2	0.87	1.12	0.93	0.19	1.6	0.25	123.	-21.4	206.	-0.06	-11.5
17	32	05	309	16.24	508.	93.	24.09	9.85	36.0	2.16	810.	565.3	094	185	4.5	0.93	1.03	1.05	0.19	1.6	0.19	161.	-25.8	238.	-0.20	-2.6
17	39	09	298	15.76	505.	83.	24.20	9.79	36.3	2.10	815.	565.5	263	187	5.0	1.07	1.21	0.99	0.20	1.5	0.24	151.	-18.1	202.	-0.19	-2.2
8-LINE GRID, 1600' MSL, WORKING SOUTH TO NORTH																										
18	04	08	297	15.56	509.	84.	24.54	9.73	37.5	2.07	816.	565.1	095	166	5.2	1.07	1.34	0.97	0.24	1.6	0.22	165.	-23.0	227.	-0.24	-1.8
18	10	46	300	16.10	508.	89.	24.57	9.72	35.9	2.11	685.	565.2	264	167	5.2	0.96	1.29	0.89	0.18	1.4	0.17	117.	-19.0	207.	-0.20	-1.8
18	17	38	304	15.90	510.	95.	24.65	9.53	34.1	2.29	698.	564.9	095	158	4.7	1.06	1.30	0.82	0.16	1.5	0.24	90.	-16.5	191.	-0.21	-1.4
18	24	33	296	16.12	509.	97.	24.72	9.66	34.7	2.08	659.	563.9	264	158	4.9	0.93	1.22	0.94	0.19	1.6	0.19	130.	-21.5	226.	-0.11	-5.0
18	31	32	314	16.27	510.	98.	24.88	9.72	38.5	1.95	798.	562.9	093	158	4.6	0.88	1.10	0.84	0.19	1.6	0.17	112.	-18.3	181.	-0.16	-2.8
18	38	29	298	16.05	506.	100.	24.98	9.65	38.6	2.00	859.	563.3	264	164	4.6	0.94	1.22	1.04	0.22	1.2	0.15	170.	-18.1	248.	-0.26	-1.9
18	45	03	303	15.61	505.	101.	25.06	9.63	40.2	1.94	871.	563.0	095	163	4.4	1.07	1.35	1.05	0.25	1.2	0.13	206.	-15.5	174.	-0.34	-1.6
18	51	55	294	16.14	508.	135.	25.06	9.47	37.7	1.82	752.	562.2	264	171	4.5	1.00	1.21	1.21	0.18	1.0	0.13	156.	-11.1	172.	-0.13	-7.1
RUNS OVER RESERVOIR																										
19	13	33	43	2.79	423.	83.	26.16	9.46	23.6	0.59	827.	570.7	272	176	6.0	1.08	1.05	0.87	0.09	0.6	0.15	5.	1.9	144.	-0.22	-0.2
19	15	32	49	2.88	431.	92.	26.17	9.46	23.5	0.55	828.	570.5	101	161	4.7	0.91	0.88	0.88	0.14	0.6	0.16	91.	-4.6	142.	-0.06	-7.8
REGIONAL RUN 500' AGL																										
19	26	28	603	38.15	574.	153.	24.81	9.22	36.7	1.88	674.	557.6	236	166	5.7	1.03	1.27	0.95	0.16	1.2	0.16	99.	-13.1	148.	-0.09	-9.2
19	36	35	651	40.59	559.	156.	24.64	10.20	38.0	1.40	615.	555.7	236	185	6.3	1.09	1.07	1.05	0.18	1.0	0.09	134.	-8.3	90.	-0.23	-2.7

TABLE 9(p): TWIN OTTER DATA - FIFE89 FLIGHT 16 - 12 AUGUST, 1989

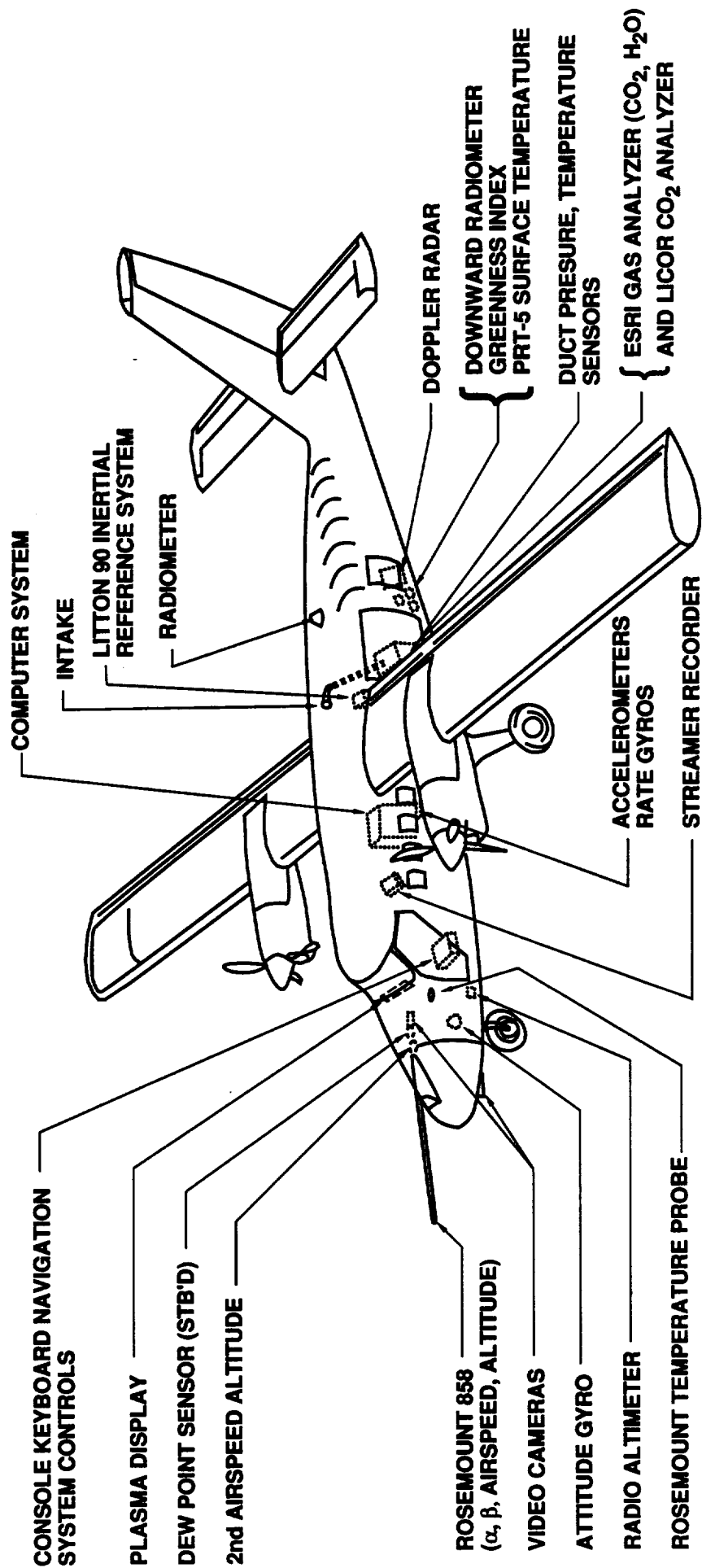


FIG. 1: NAE TWIN OTTER ATMOSPHERIC RESEARCH AIRCRAFT AS INSTRUMENTED FOR GASEOUS EXCHANGE MEASUREMENT

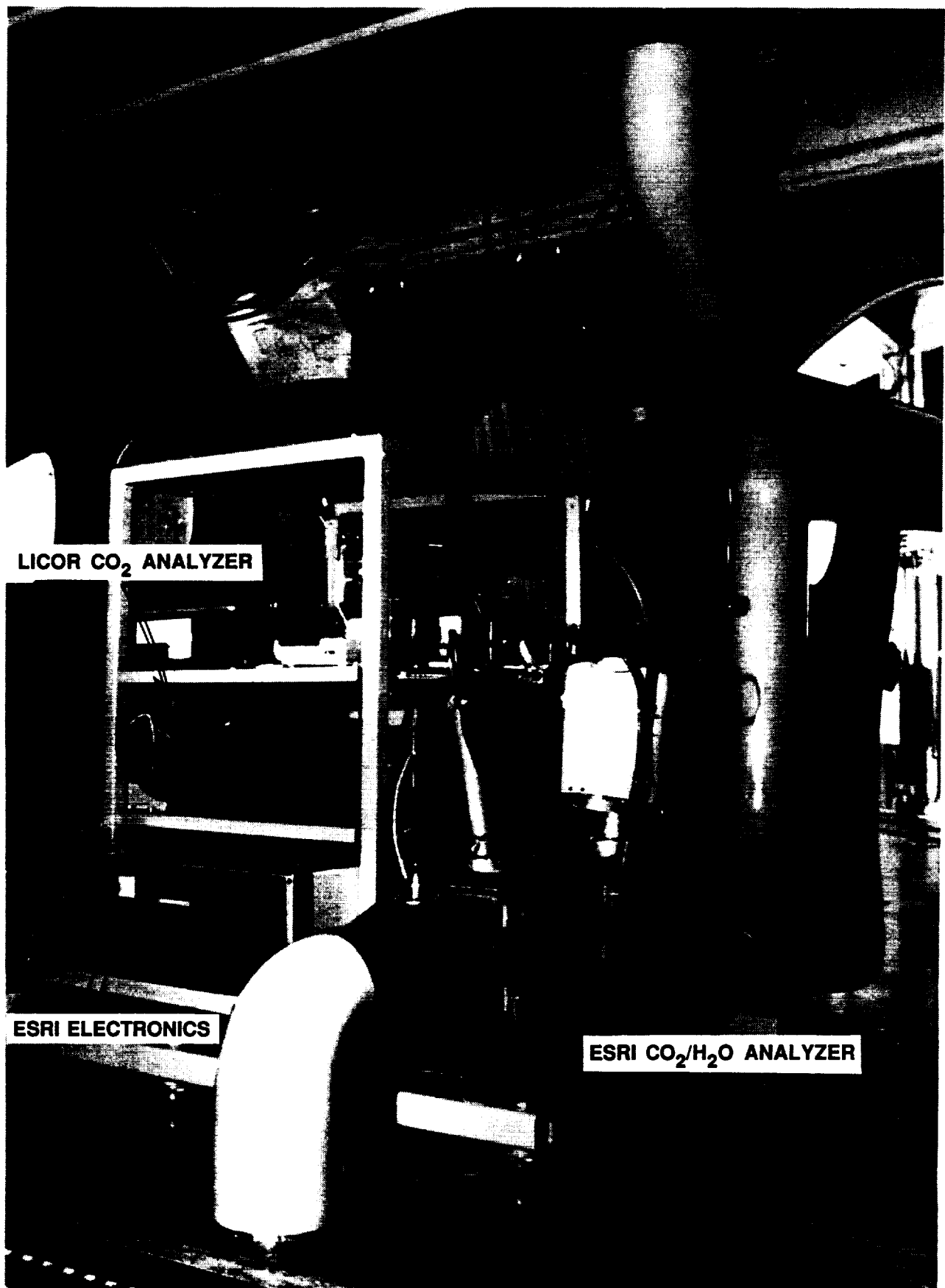
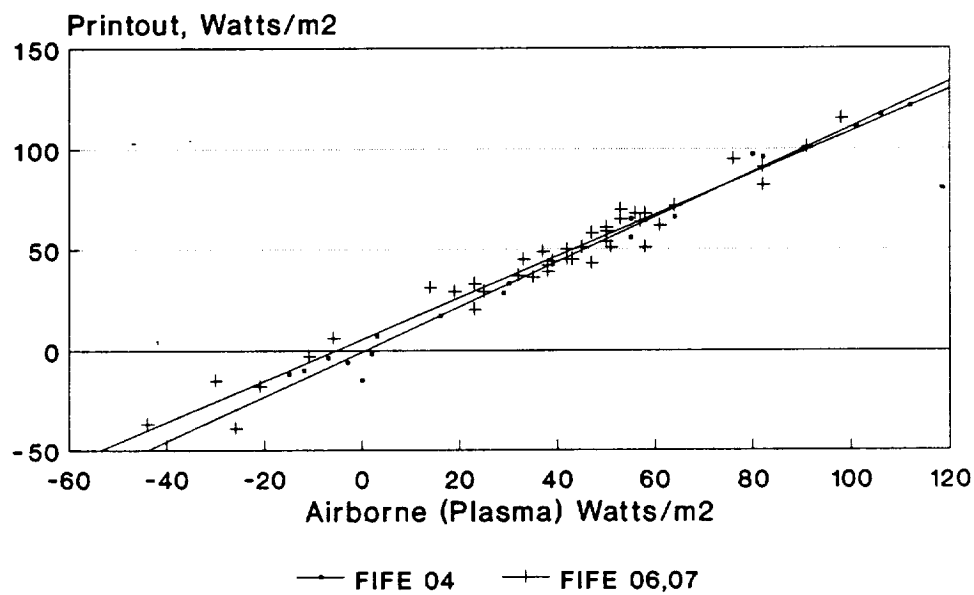


FIG. 2: DUCT AND GAS ANALYZERS

FIGURE 3: PLAYBACK VS AIRBORNE FLUX
Sensible Heat Flux



Module POK9Ci; HP-filtered data

CO₂ Fluxes

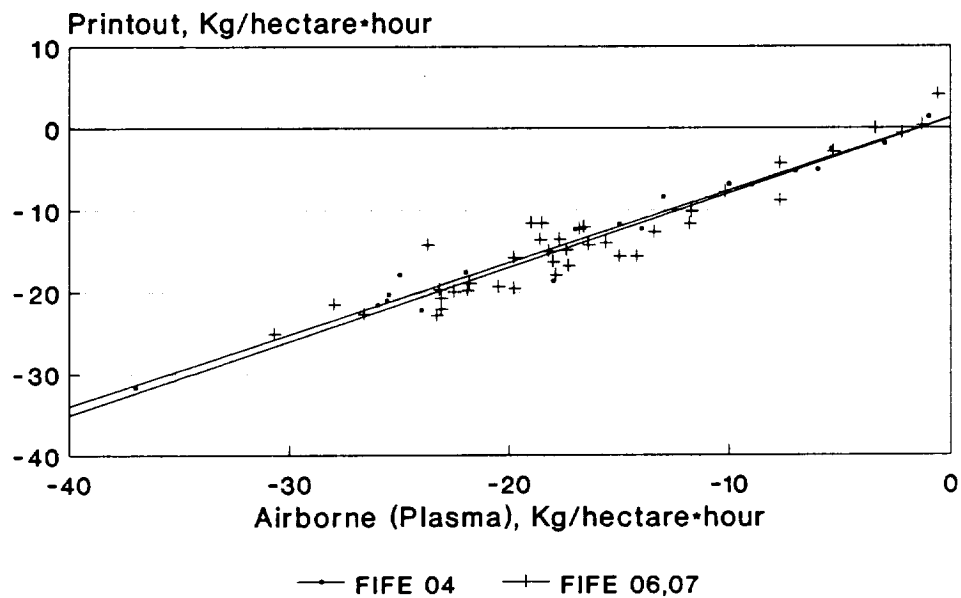
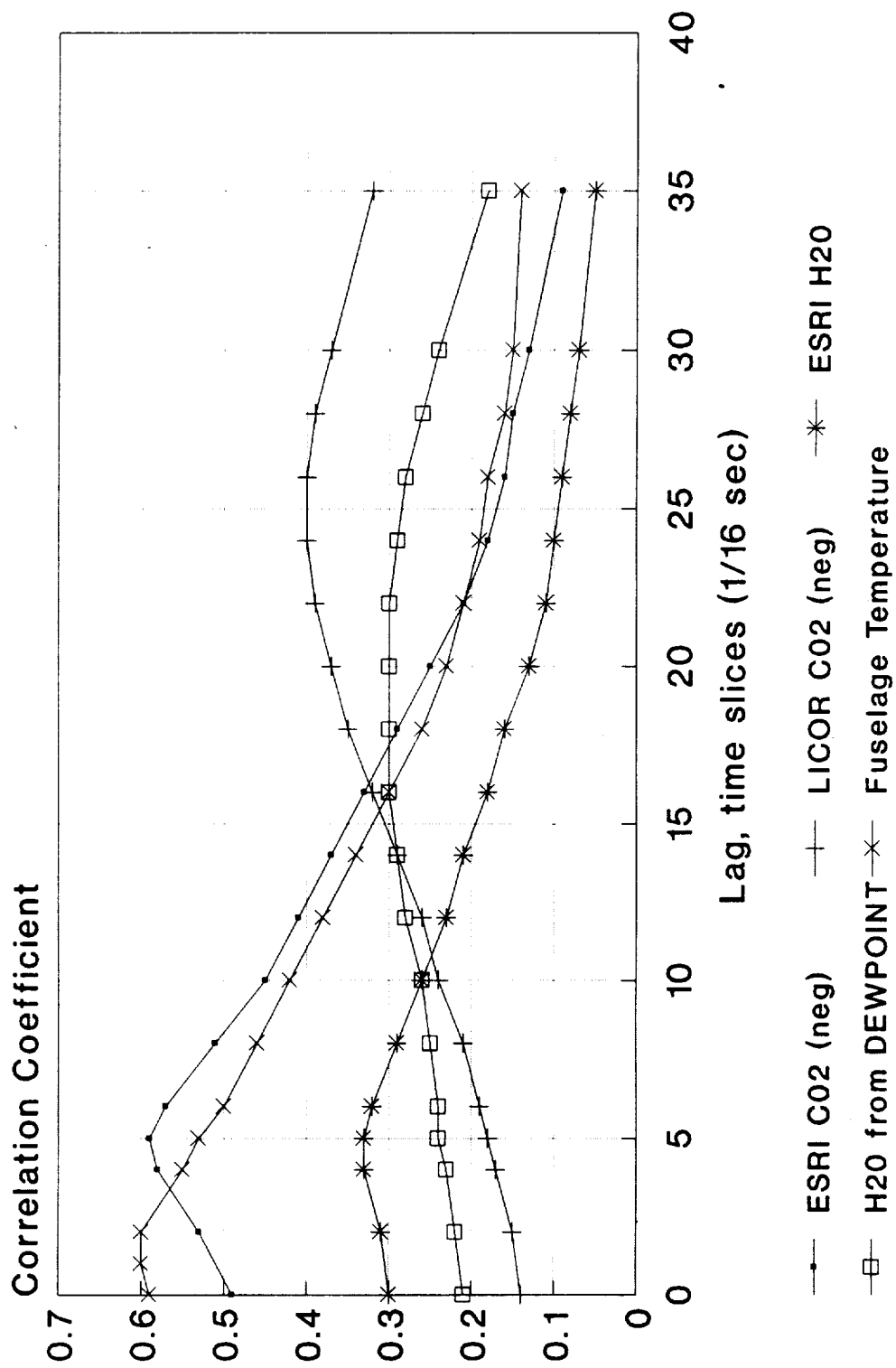
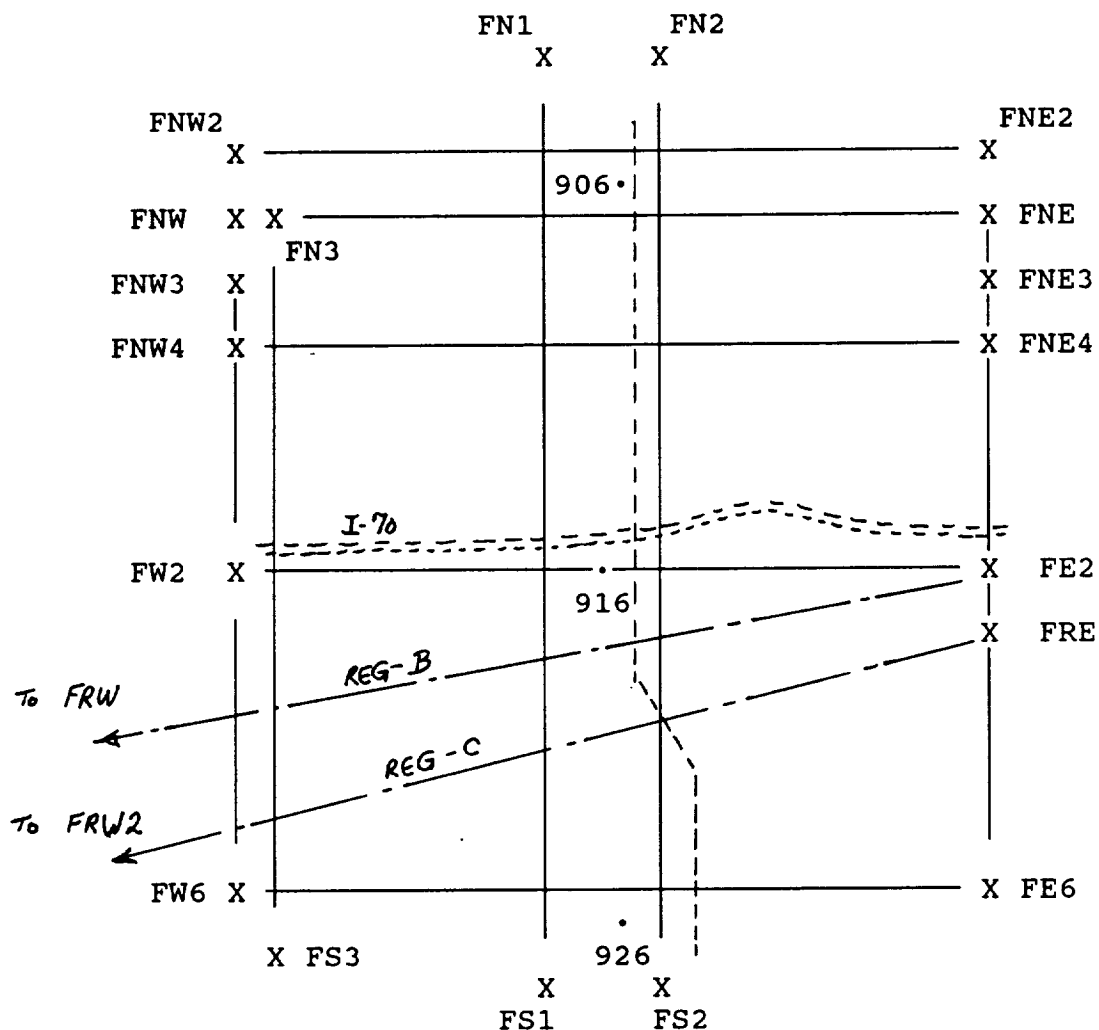


Figure 4: Time Lag Study





Label	Latitude	Longitude	Label	Latitude	Longitude
FN1	39 07.0	96 33.0	FN2	39 07.0	96 31.0
FNW2	39 05.8	96 37.0	FNE2	39 05.8	96 26.3
FNW	39 05.3	96 37.0	FNE	39 05.3	96 26.3
FN3	39 05.3	96 26.0	FNE3	39 05.3	96 26.3
FNW3	39 05.3	96 37.0	FNE4	39 04.8	96 26.3
FNW4	39 04.8	96 37.0	FRE (FE2)	39 02.8	96 26.3
FW2	39 03.3	96 37.0	FE6	38 59.2	96 26.3
FW6	38 59.2	96 37.0	FS2	38 58.4	96 31.5
FS1	38 58.0	96 33.0			
FS3	38 58.4	96 36.0			
FRW	38 49.0	97 16.0	West point of Regional Run B		
FRW2	38 42.0	97 13.4	West Point of regional Run C		

FIGURE 5: NAVIGATION WAYPOINTS - FIFE 89

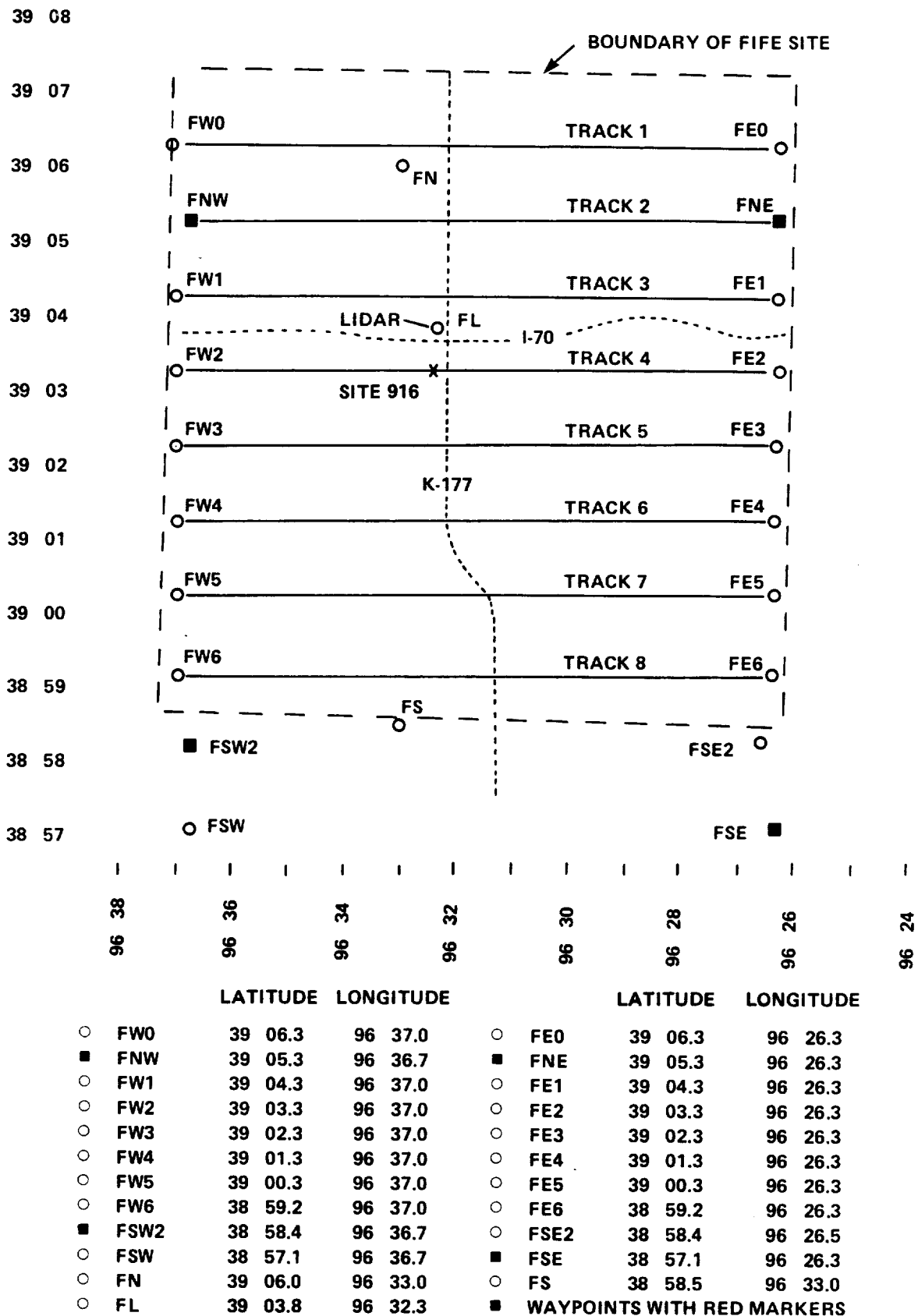


FIG. 6: WAYPOINTS AND TRACKS FOR GRID FLIGHT PATTERN

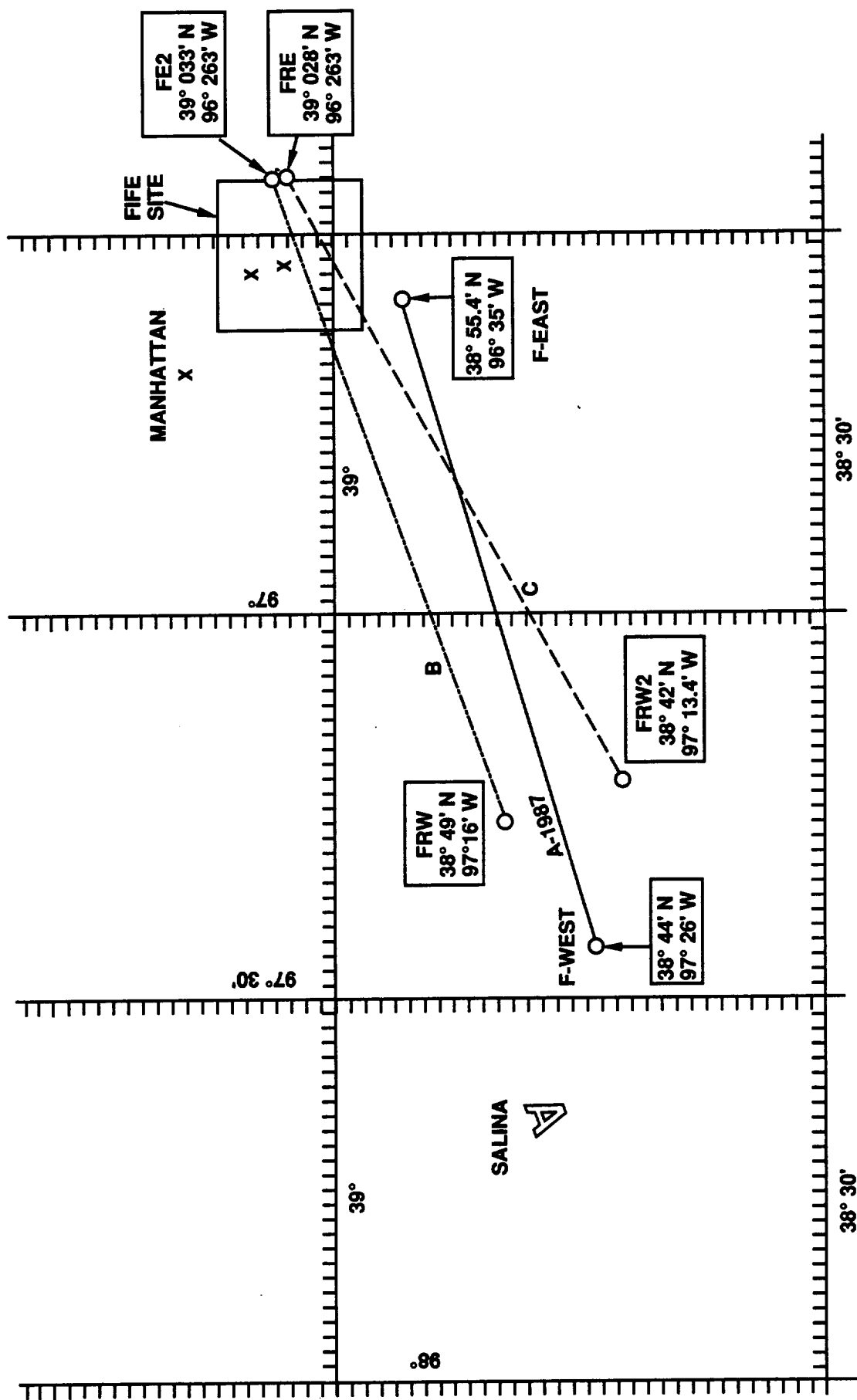
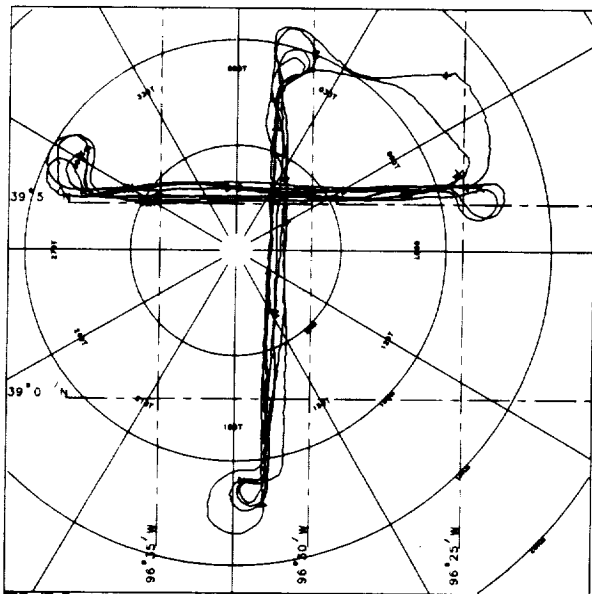


FIG. 7: THE REGIONAL RUNS

Twin Otter Track Plot
FIFE 89-01
Reference Point FIFE LIDAR
39 3 8 96 32 5

Flight Date 27-JUL-89
Segments (Files)
Start 16 450 End 18 505
Grid Oriented True N
Range rings at 5.0 km
Scale (mm/km) = 6.3963

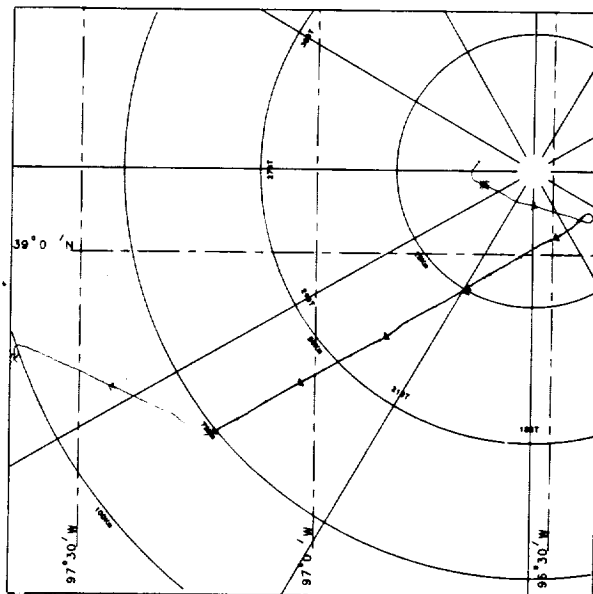
x = Start/end of file
Gaps = Loran out
+ = 5 min GMT
* = Photo event



Twin Otter Track Plot
FIFE -02, REGION C
Reference Point FIFE LIDAR
39 8.3 96 32 5

Flight Date 27-JUL-89
Segments (Files)
Start 19 1028 End 19 5023
Grid Oriented True N
Range rings at 25.0 km
Scale (mm/km) = 1.6542

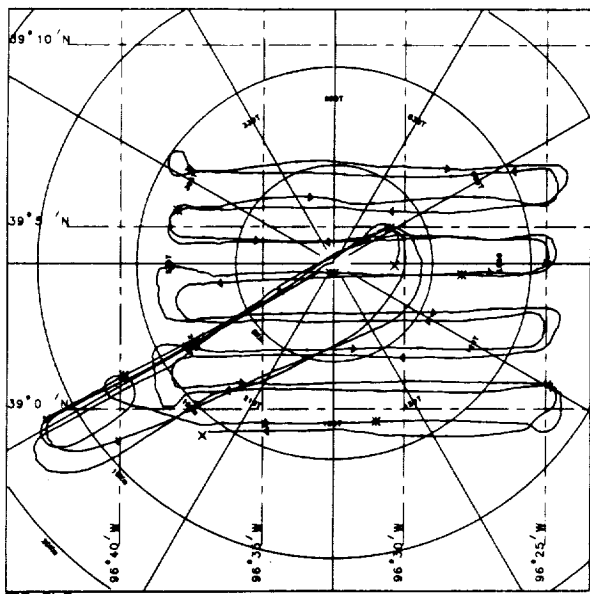
x = Start/end of file
Gaps = Loran out
+ = 5 min GMT
* = Photo event



Twin Otter Track Plot
FIFE FLT 89-03
Reference Point FIFE LIDAR
39 4 0 96 32 5

Flight Date 28-JUL-89
Segments (Files)
Start 15 1101 End 17 2804
Grid Oriented True N
Range rings at 5.0 km
Scale (mm/km) = 6.0000

x = Start/end of file
Gaps = Loran out
+ = 5 min GMT
* = Photo event



Twin Otter Track Plot
FIFE FLIGHT 04
Reference Point FIFE LIDAR
39 4 0 96 32 5

Flight Date 02-AUG-89
Segments (Files)
Start 15 2801 End 17 4404
Grid Oriented True N
Range rings at 5.0 km
Scale (mm/km) = 6.3963

x = Start/end of file
Gaps = Loran out
+ = 5 min GMT
* = Photo event

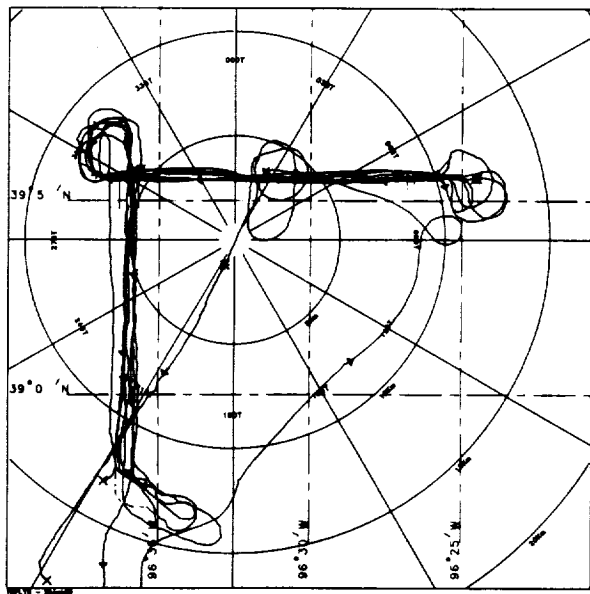


FIG. 8(a): FLIGHT TRACK PLOTS - FLIGHTS 01 TO 04

Twin Otter Track Plot
FIFE 89-05
Reference Point FIFE LIDAR
39 4.0 96 32.5

Flight Date 03-AUG-89

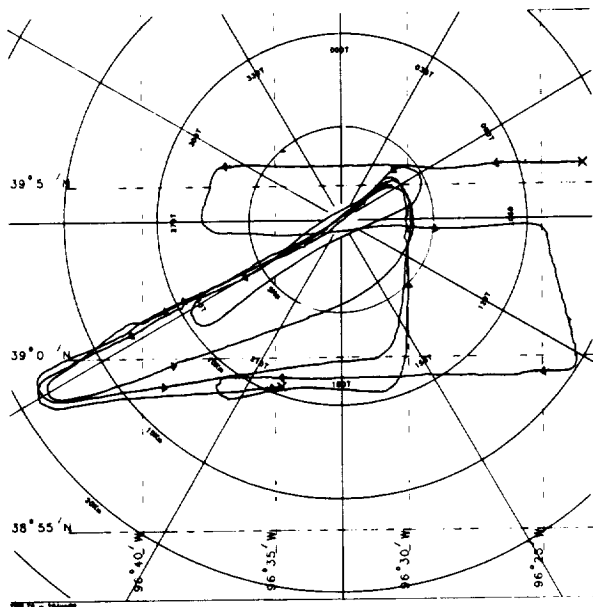
Segments (Files):
Start 17 4829 End 19 504

Grid Oriented True N

Range rings at 5.0 km

Scale (mm/km) = 5.6438

X = Start/end of file
Gaps = Loran out
+ = 5 min GMT
* = Photo event



Twin Otter Track Plot
FIFE 8906
Reference Point FIFE LIDAR
39 4.5 96 31.9

Flight Date 04-AUG-89

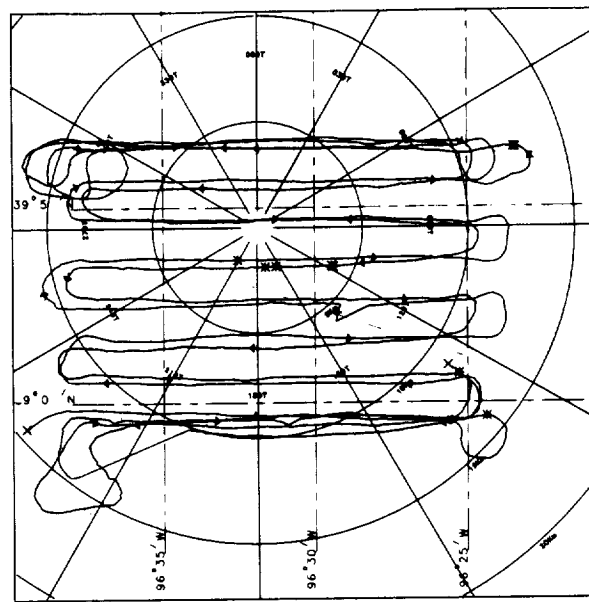
Segments (Files):
Start 14 4200 End 17 1605

Grid Oriented True N

Range rings at 5.0 km

Scale (mm/km) = 6.3963

X = Start/end of file
Gaps = Loran out
+ = 5 min GMT
* = Photo event



Twin Otter Track Plot
FIFE 89-07
Reference Point FIFE LIDAR
39 4.5 96 31.9

Flight Date 04-AUG-89

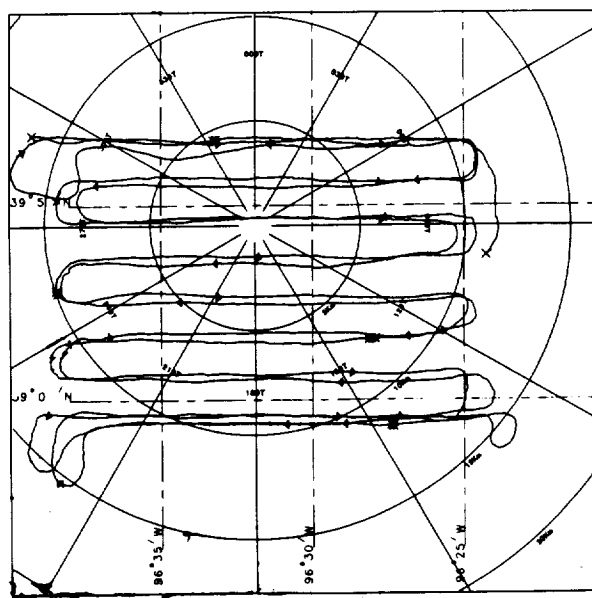
Segments (Files):
Start 18 3703 End 20 4806

Grid Oriented True N

Range rings at 5.0 km

Scale (mm/km) = 6.3963

X = Start/end of file
Gaps = Loran out
+ = 5 min GMT
* = Photo event



Twin Otter Track Plot
FIFE 89-08
Reference Point FIFE LIDAR
39 4.5 96 31.9

Flight Date 06-AUG-89

Segments (Files):
Start 15 2802 End 18 3028

Grid Oriented True N

Range rings at 5.0 km

Scale (mm/km) = 6.3963

X = Start/end of file
Gaps = Loran out
+ = 5 min GMT
* = Photo event

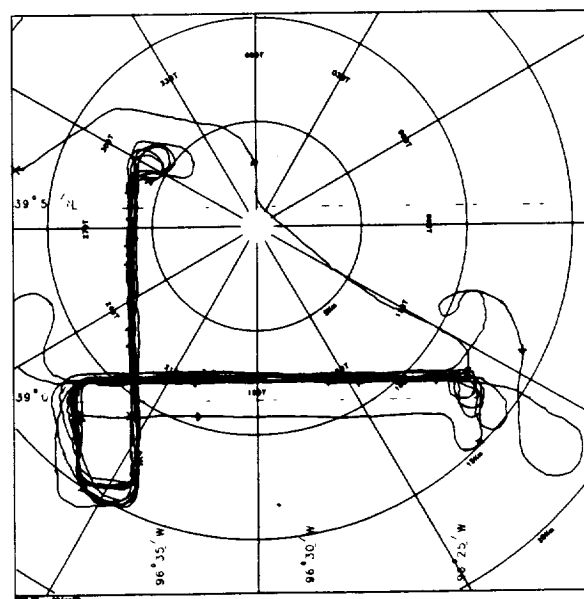


FIG. 8(b): FLIGHT TRACK PLOTS - FLIGHTS 05 TO 08

Twin Otter Track Plot
FIFE 89-09

Reference Point FIFE LIDAR
39 4.5 96 31.9

Flight Date 06-AUG-89

Segments (Files):

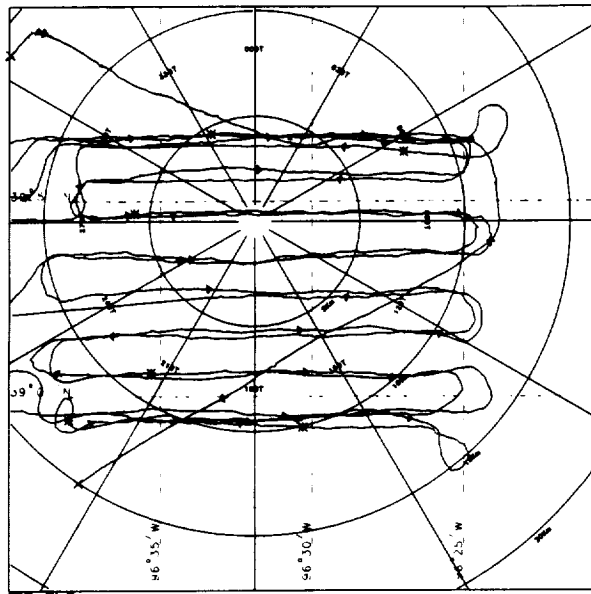
Start 19 2901 End 22 1203

Grid Oriented True N

Range rings at 5.0 km

Scale (mm/km) = 6.3963

x = Start/end of file
+ = Loran out
+ = 5 min GMT
* = Photo event



Twin Otter Track Plot
FIFE 89-10

Reference Point FIFE LIDAR
39 4.5 96 31.9

Flight Date 07-AUG-89

Segments (Files):

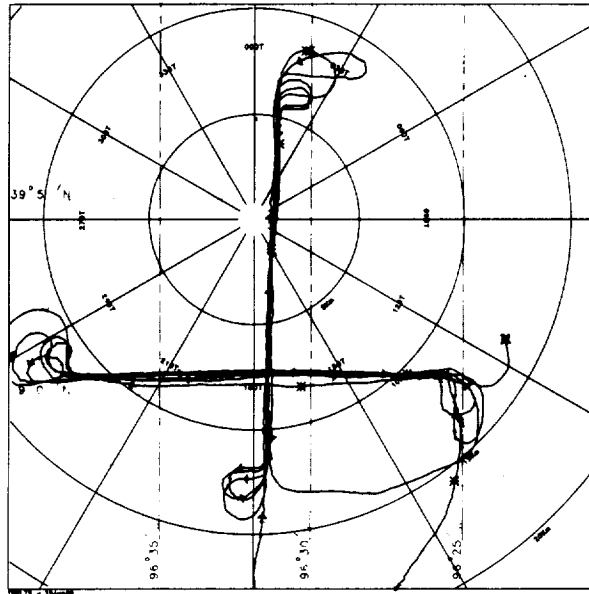
Start 15 5000 End 18 605

Grid Oriented True N

Range rings at 5.0 km

Scale (mm/km) = 6.3963

x = Start/end of file
+ = Loran out
+ = 5 min GMT
* = Photo event



Twin Otter Track Plot
FIFE 89-11

Reference Point FIFE LIDAR
39 4.5 96 31.9

Flight Date 08-AUG-89

Segments (Files):

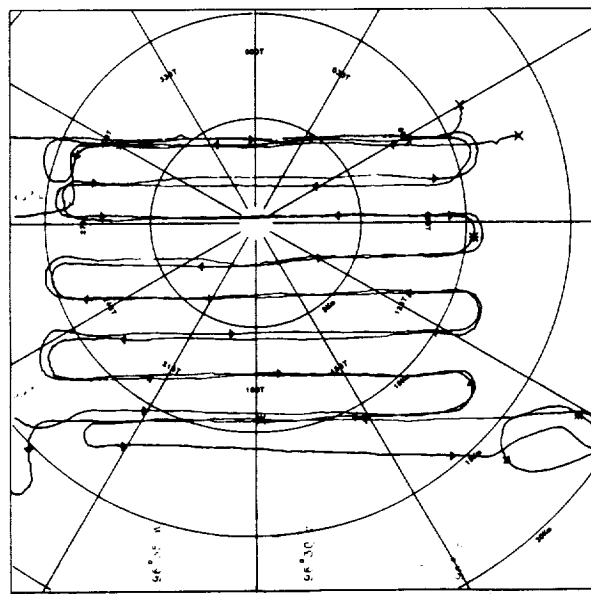
Start 15 5300 End 18 2308

Grid Oriented True N

Range rings at 5.0 km

Scale (mm/km) = 6.3963

x = Start/end of file
+ = Loran out
+ = 5 min GMT
* = Photo event



Twin Otter Track Plot
FIFE 89-12

Reference Point FIFE LIDAR
39 4.5 96 31.9

Flight Date 08-AUG-89

Segments (Files):

Start 19 5000 End 21 4206

Grid Oriented True N

Range rings at 5.0 km

Scale (mm/km) = 6.3963

x = Start/end of file
+ = Loran out
+ = 5 min GMT
* = Photo event

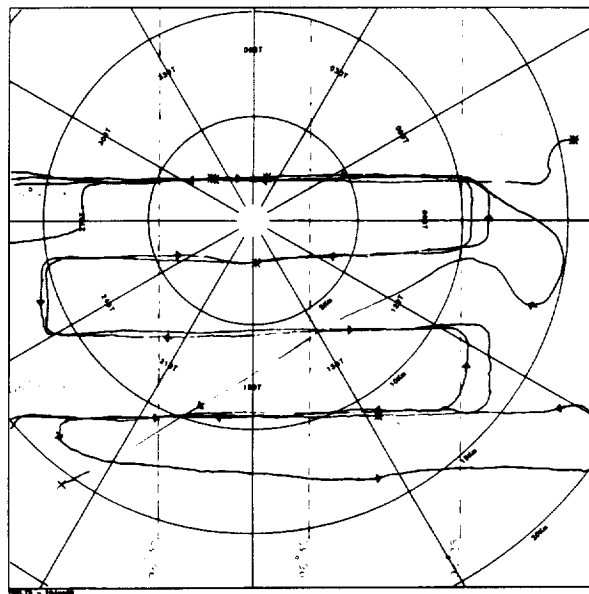


FIG. 8(c): FLIGHT TRACK PLOTS - FLIGHTS 09 TO 12

Twin Otter Track Plot

FIFE 89-13

Reference Point FIFE LIDAR

39 4.5 96 31.9

Flight Date 10-AUG-89

Segments (Files):

Start 16 3601 End 18 3603

Grid Oriented True N

Range rings at 5.0 km

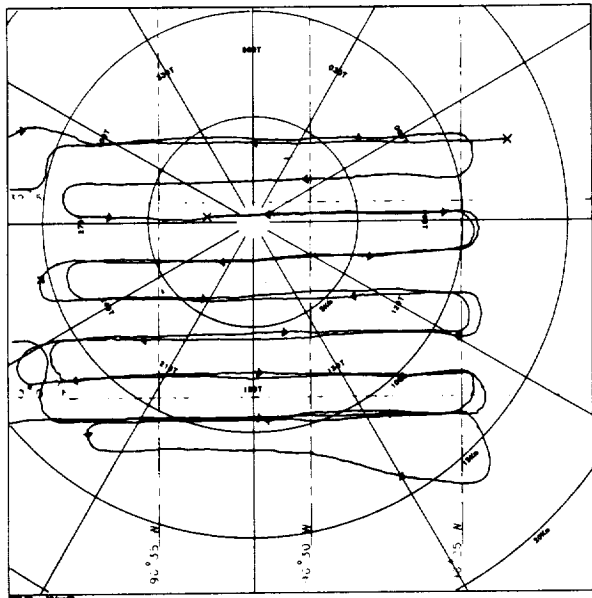
Scale (mm/km) = 6.3963

x = Start/end of file

Gaps = Loran out

+ = 5 min GMT

* = Photo event



Twin Otter Track Plot

FIFE 89-14, NIGHT

Reference Point FIFE LIDAR

39 4.5 96 31.9

Flight Date 10-AUG-89

Segments (Files):

Start 1 1803 End 2 4406

Grid Oriented True N

Range rings at 5.0 km

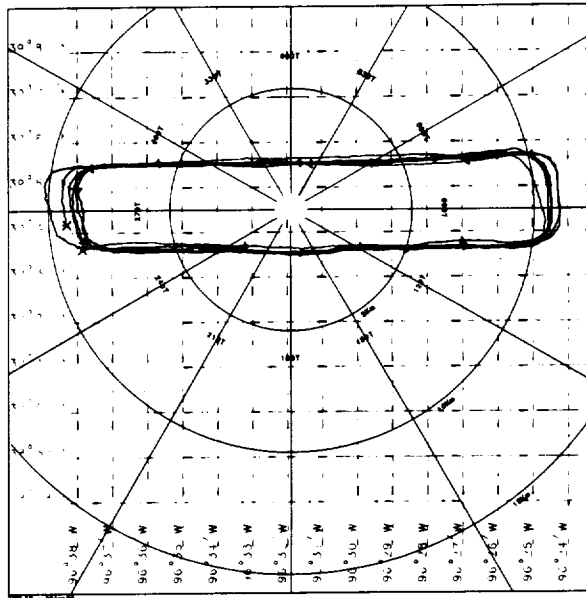
Scale (mm/km) = 7.3803

x = Start/end of file

Gaps = Loran out

+ = 5 min GMT

* = Photo event



Twin Otter Track Plot

FIFE 89-15

Reference Point FIFE LIDAR

39 4.5 96 31.9

Flight Date 11-AUG-89

Segments (Files):

Start 17 803 End 19 3905

Grid Oriented True N

Range rings at 5.0 km

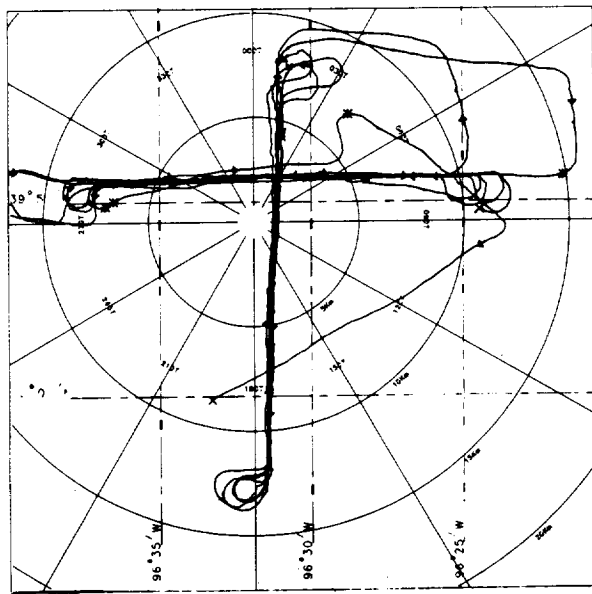
Scale (mm/km) = 6.3963

x = Start/end of file

Gaps = Loran out

+ = 5 min GMT

* = Photo event



Twin Otter Track Plot

FIFE 89-16

Reference Point FIFE 89-16

39 4.5 96 31.9

Flight Date 12-AUG-89

Segments (Files):

Start 16 4101 End 19 5816

Grid Oriented True N

Range rings at 5.0 km

Scale (mm/km) = 4.5688

x = Start/end of file

Gaps = Loran out

+ = 5 min GMT

* = Photo event

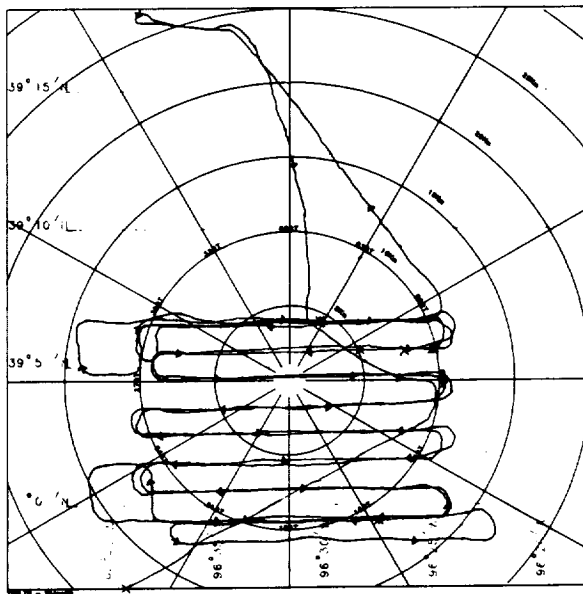


FIG. 8(d): FLIGHT TRACK PLOTS - FLIGHTS 13 TO 16

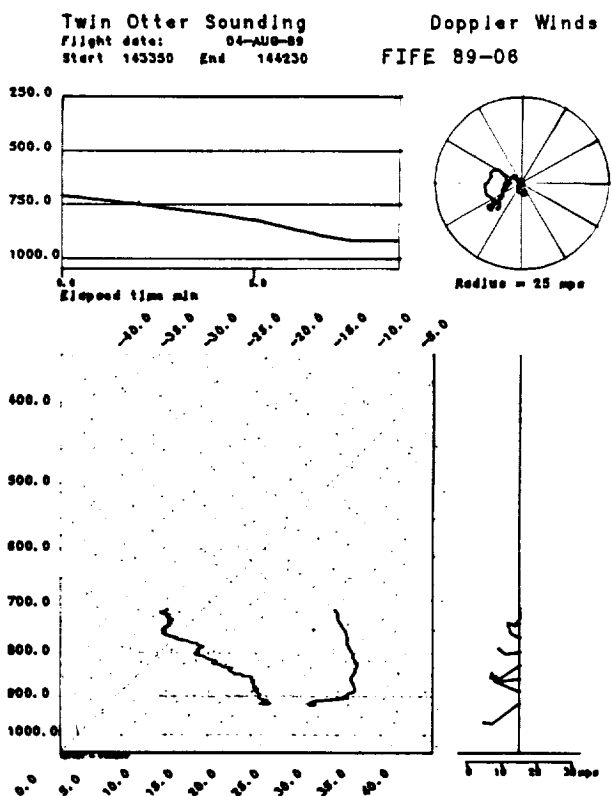
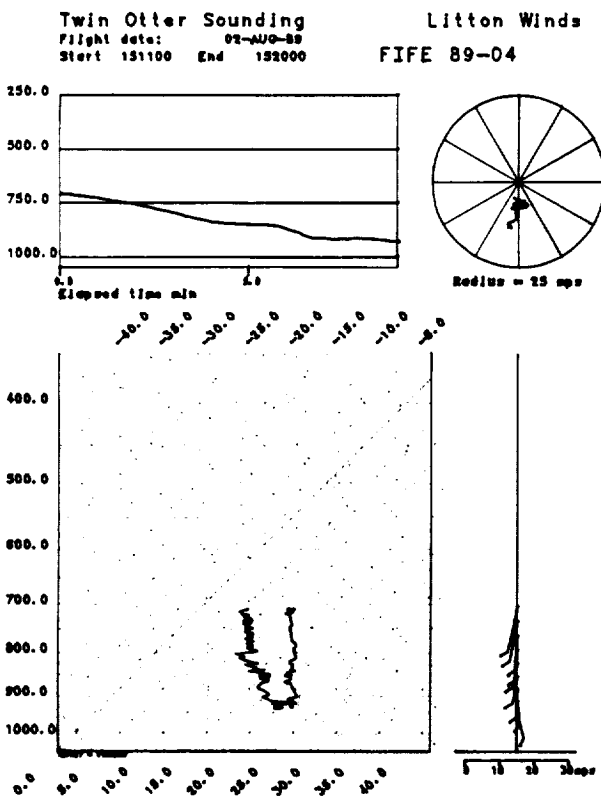
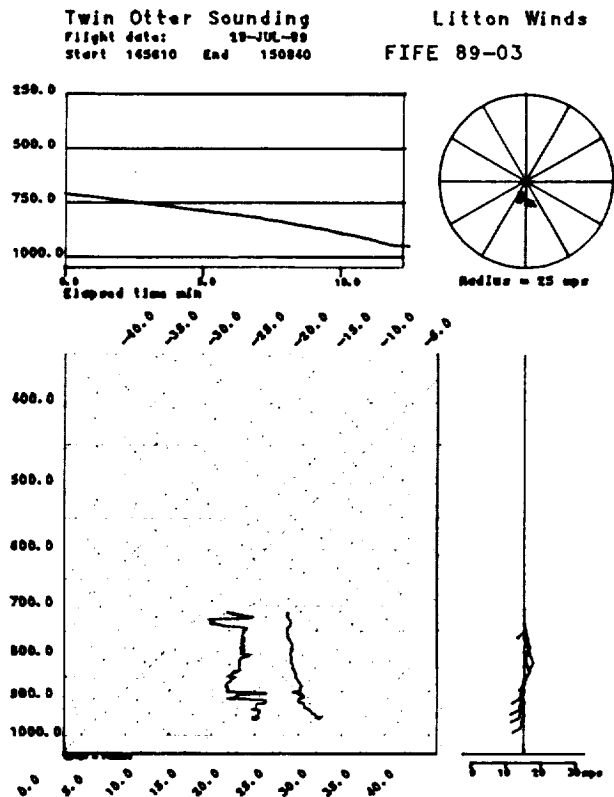
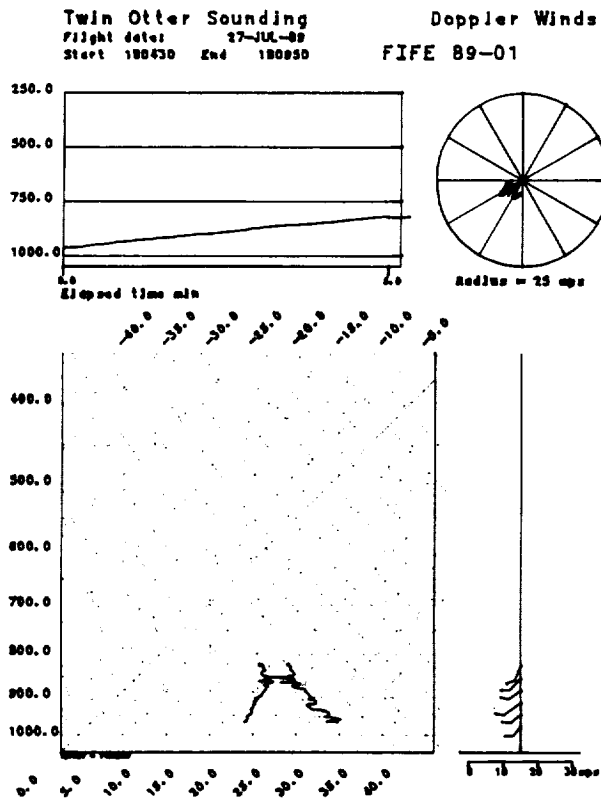


FIG. 9(a): TWIN OTTER SOUNDINGS - FLIGHTS 01, 03, 04 AND 06

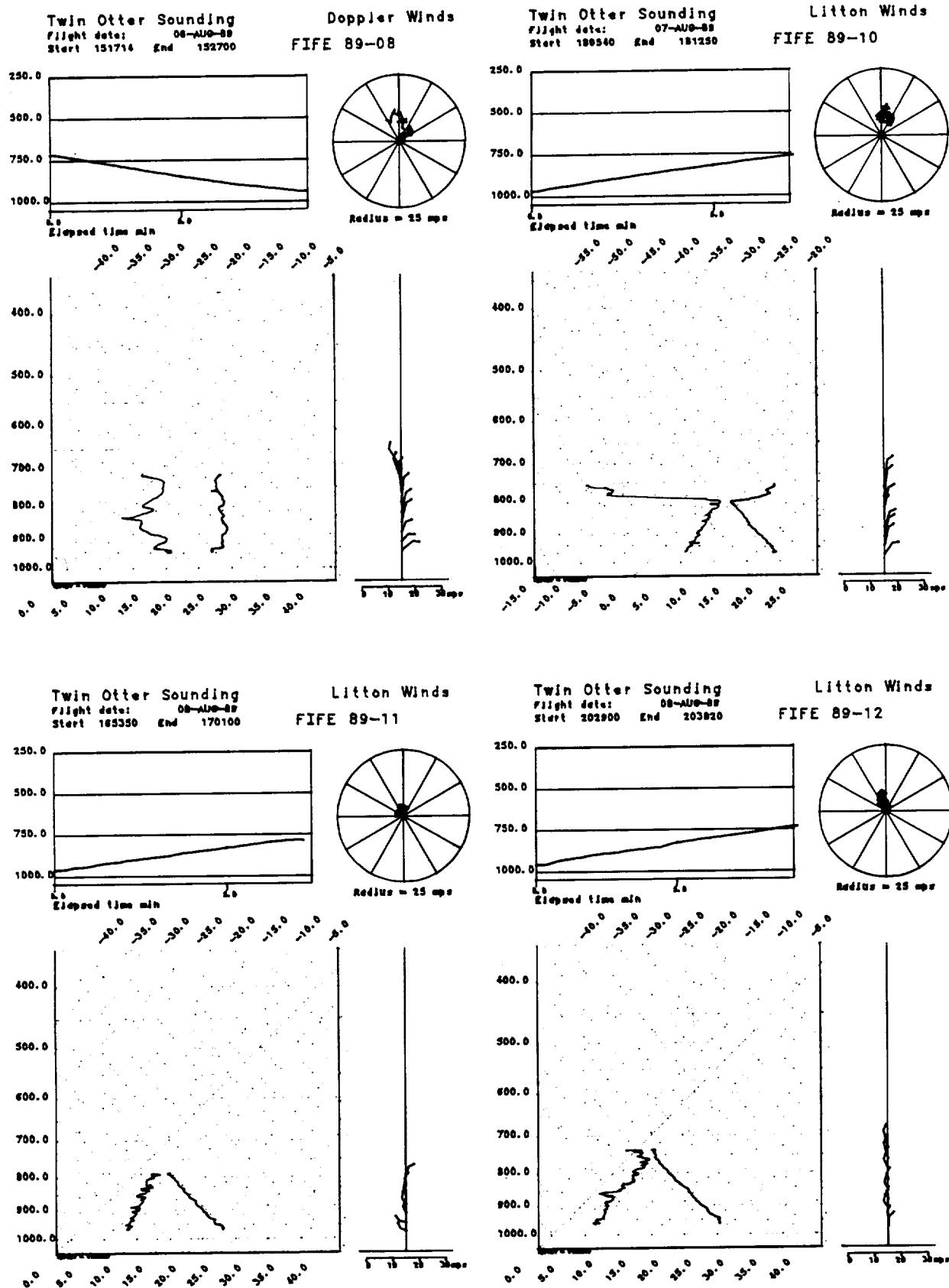


FIG. 9(b): TWIN OTTER SOUNDINGS - FLIGHTS 08, 10, 11 AND 12

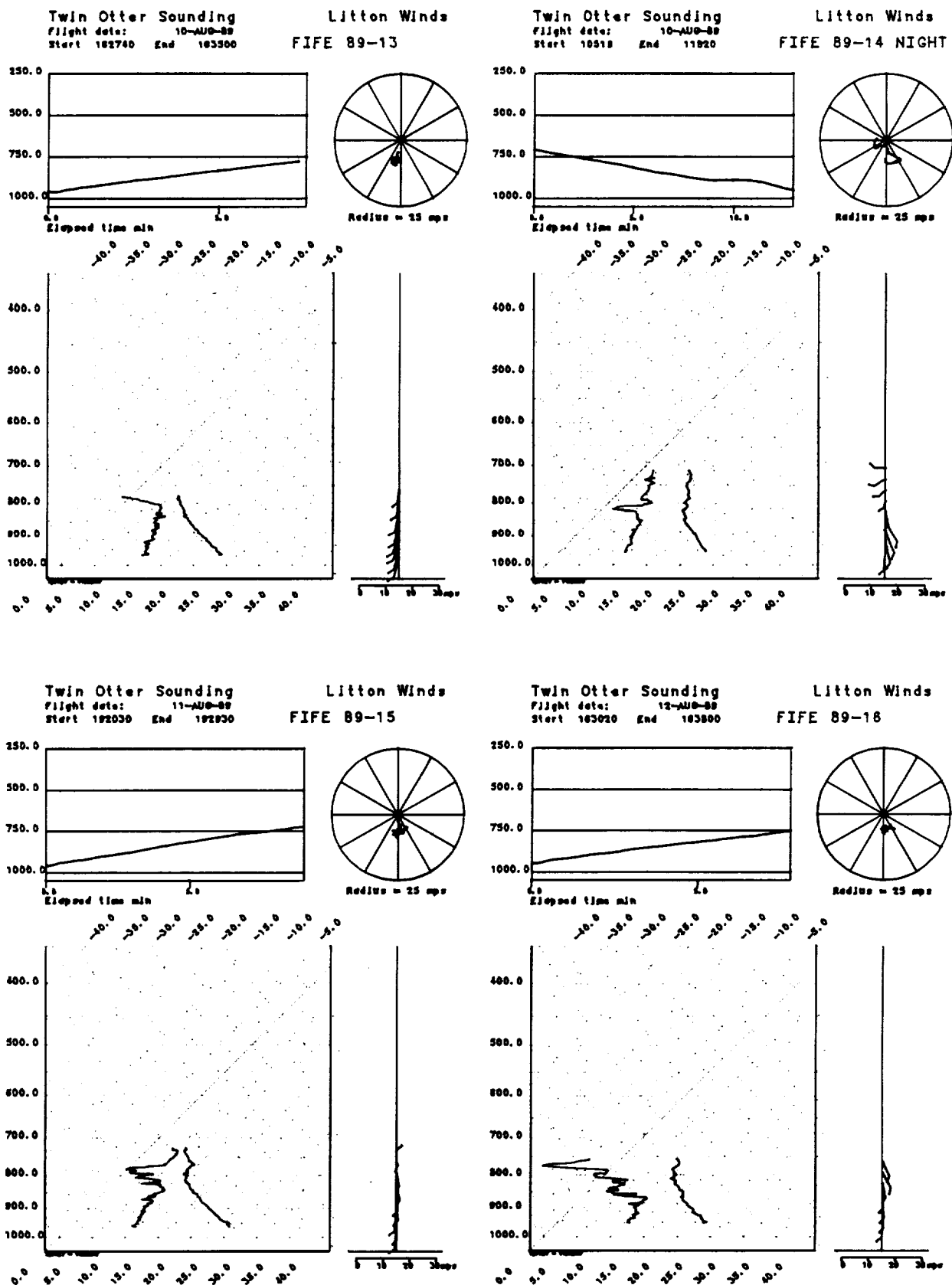
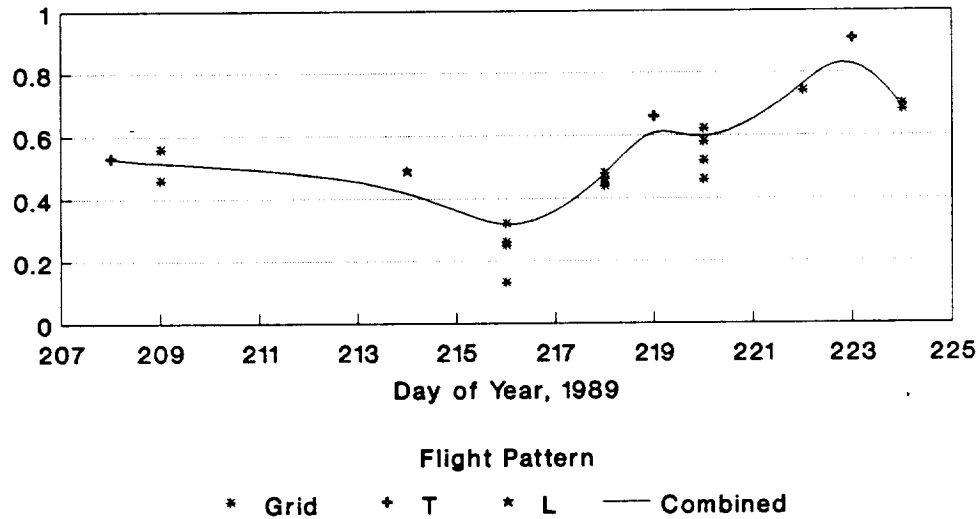


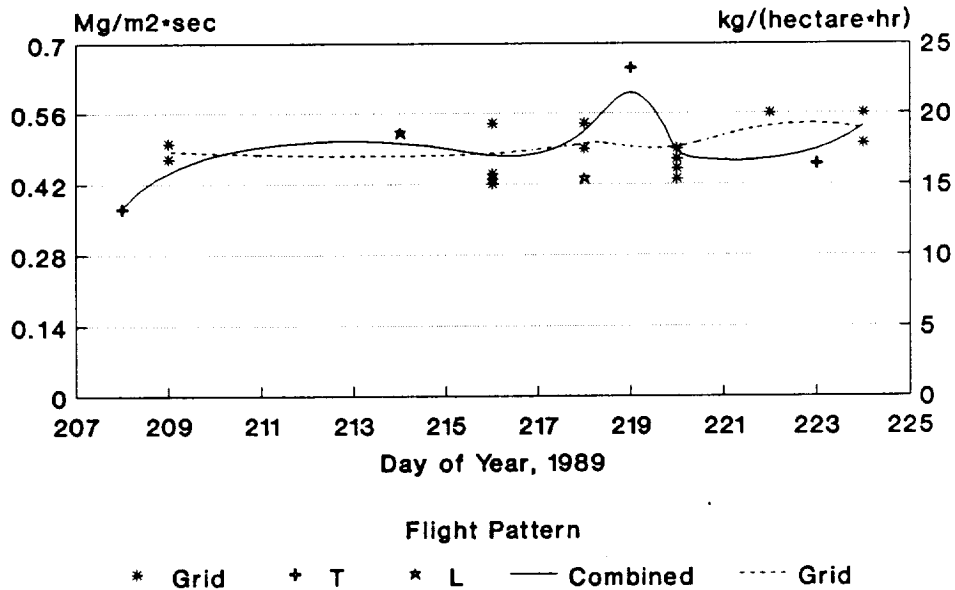
FIG. 9(c): TWIN OTTER SOUNDINGS - FLIGHTS 13 TO 16

Fig. 10: Twin Otter Flux Data
Bowen Ratio H/LE

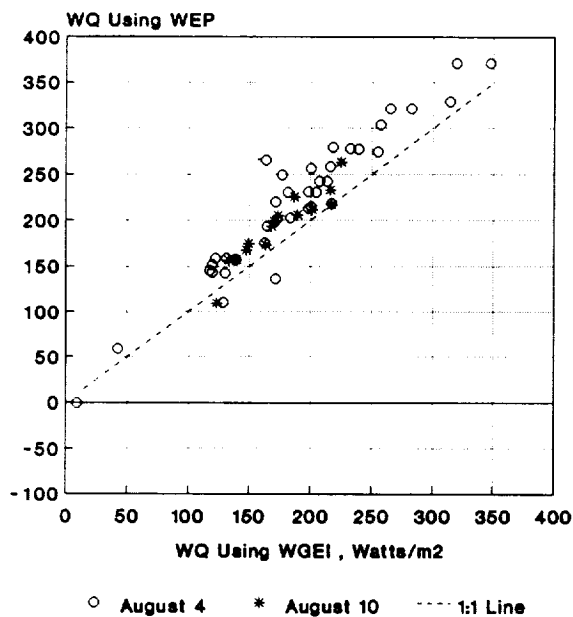


Each symbol is average of 4 to 10 runs
From data HP filtered at 5-km
All runs at 1600 ft msl (about 100m agl)

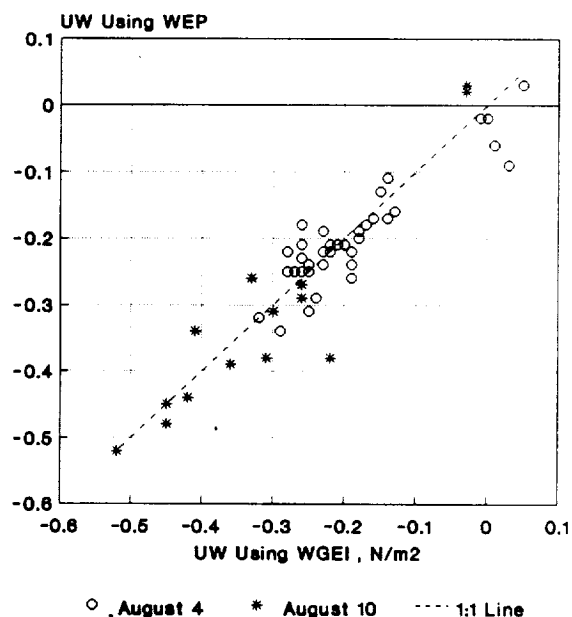
C02 Flux - 100 m Altitude



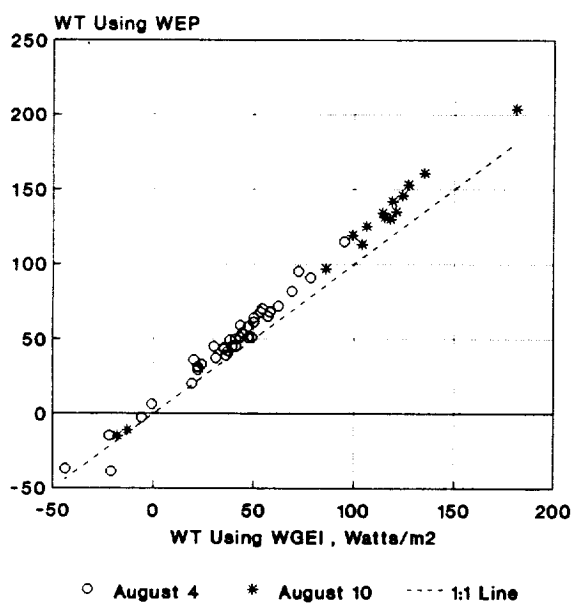
Latent Heat Flux



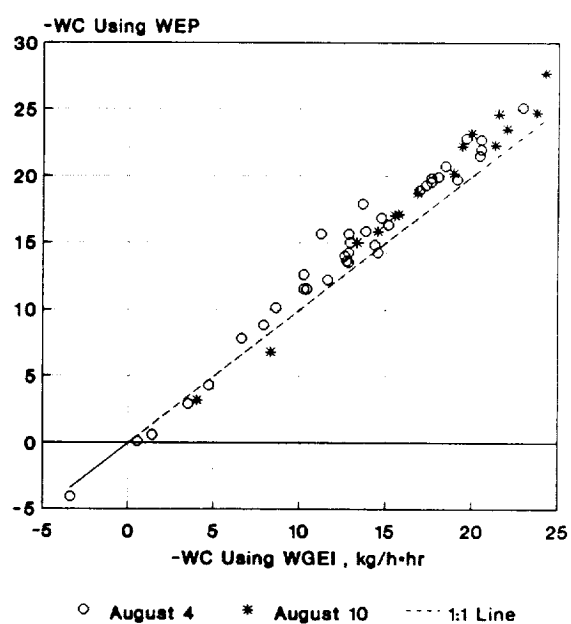
Momentum Flux



Sensible Heat Flux



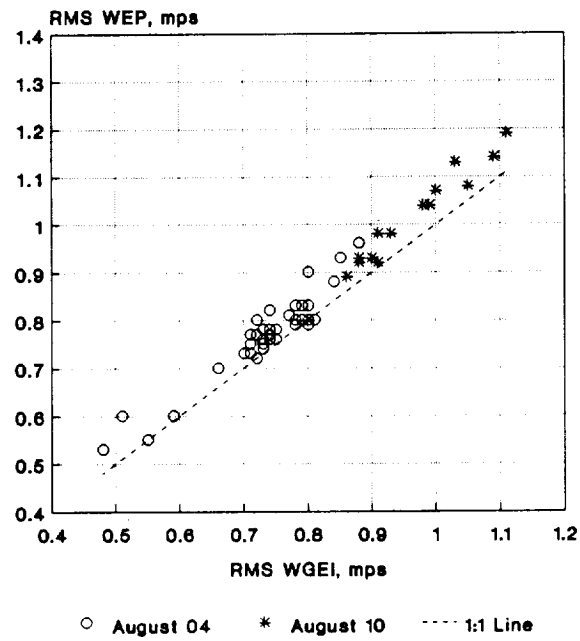
CO2 Flux



All fluxes from data that was
high-pass filtered at 0.012 Hz

Fig 11: Fluxes Using WEP vs WGEI

RMS WEP versus WGEI



HP filtered at 0.012 Hz

WC Correlation Coefficient Using WEP vs WGEI

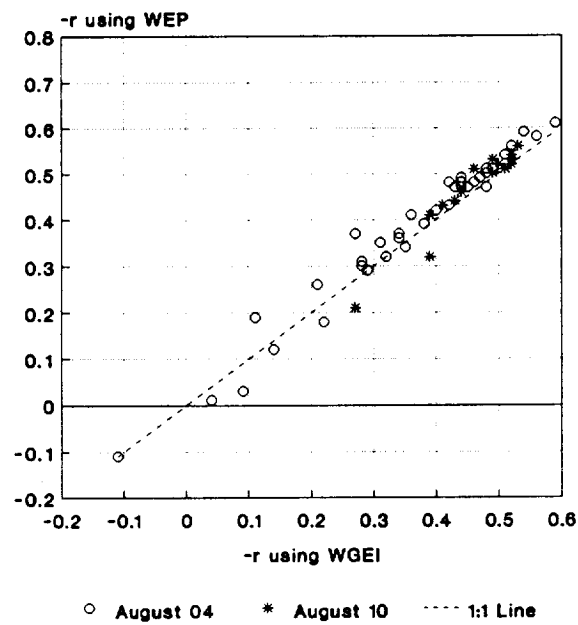
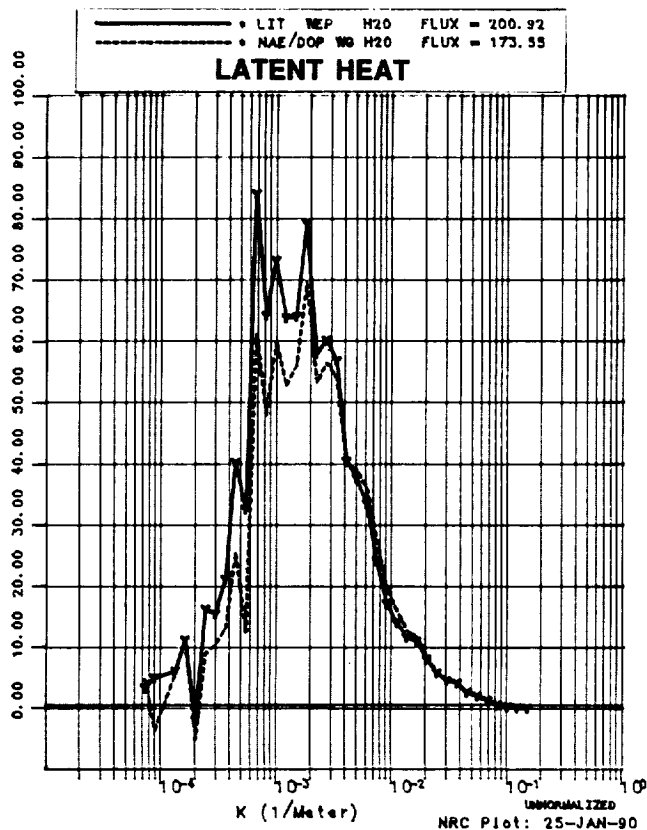
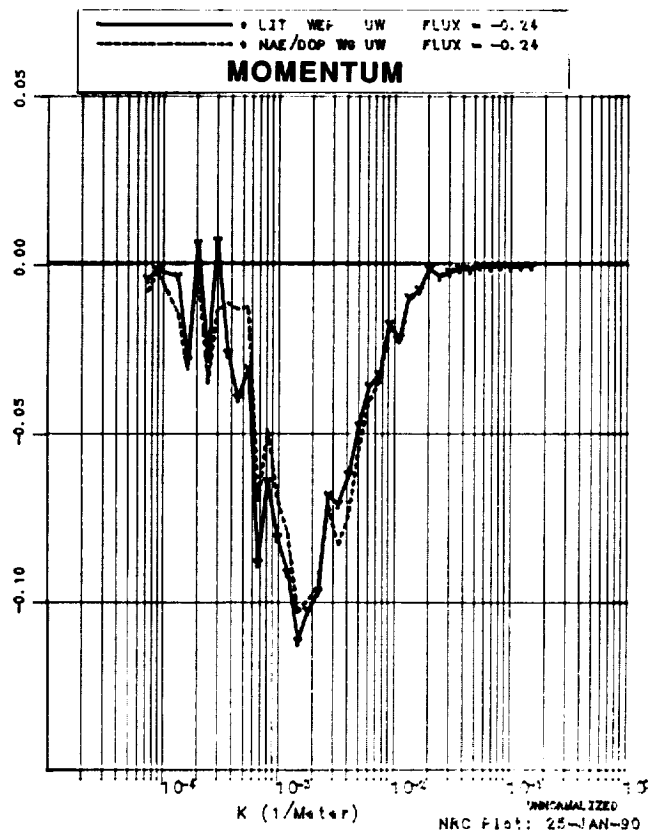


Fig 12: RMS and Correlation Coefficient

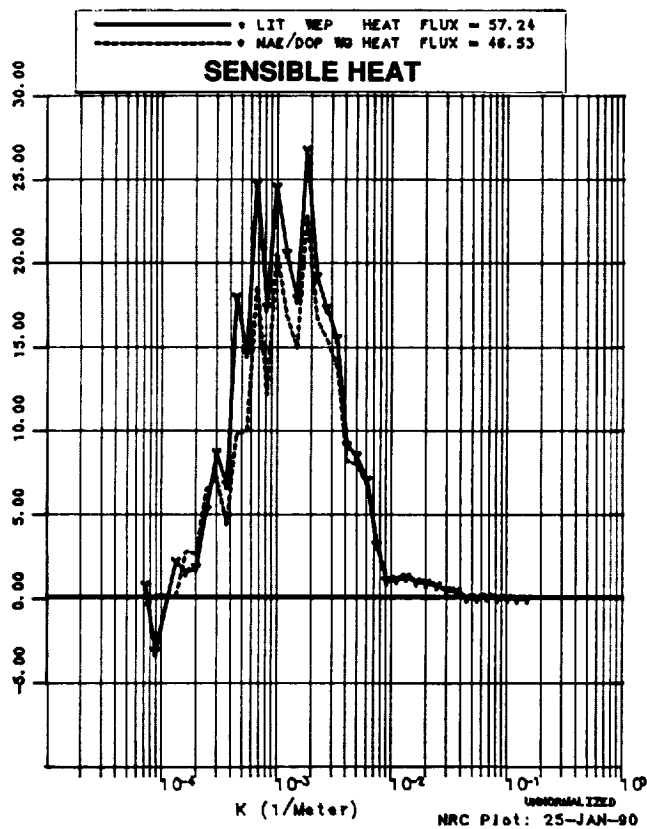
NRC/NAE TWIN OTTER COSPECTRA
FIFE 06, 4 AUGUST, DETRENDED/UNFILTERED



NRC/NAE TWIN OTTER COSPECTRA
FIFE 06, 4 AUGUST, DETRENDED/UNFILTERED



NRC/NAE TWIN OTTER COSPECTRA
FIFE 06, 4 AUGUST, DETRENDED/UNFILTERED



NRC/NAE TWIN OTTER COSPECTRA
FIFE 06, 4 AUGUST, DETRENDED/UNFILTERED

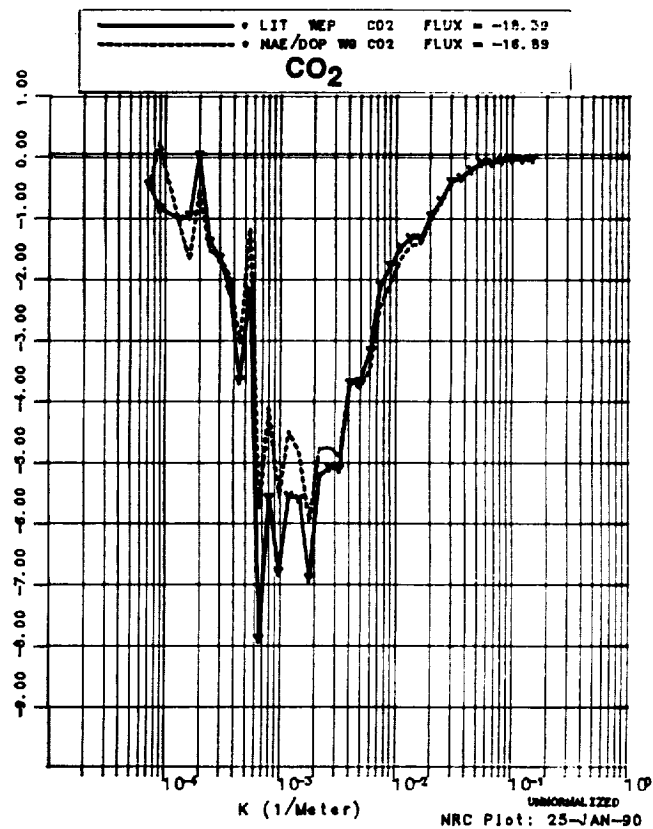
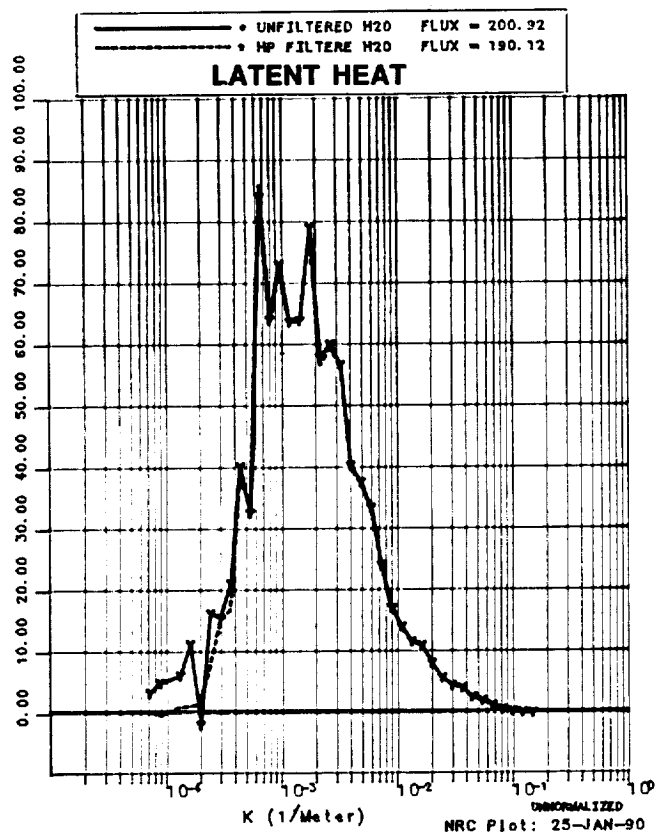
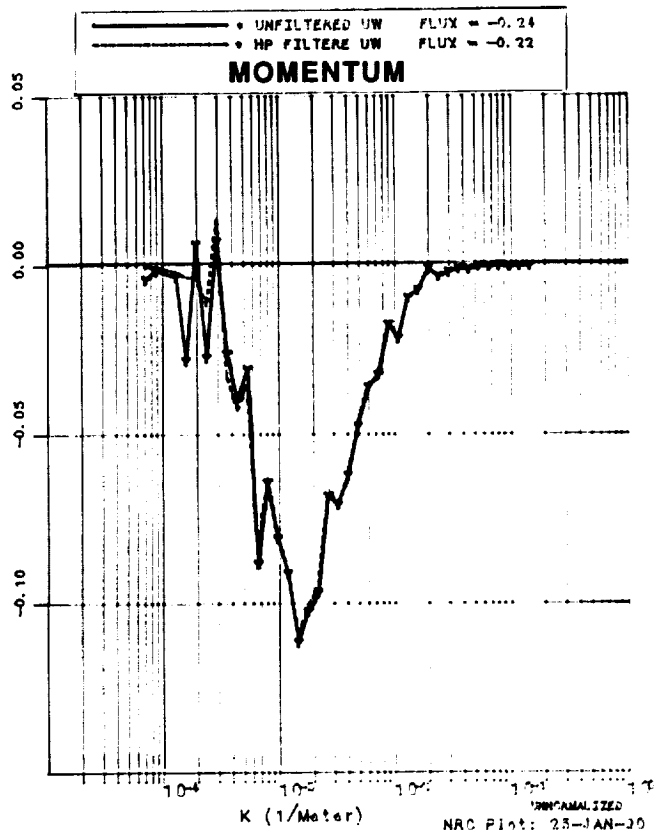


FIG. 13: COSPECTRA USING WEP AND WGEI

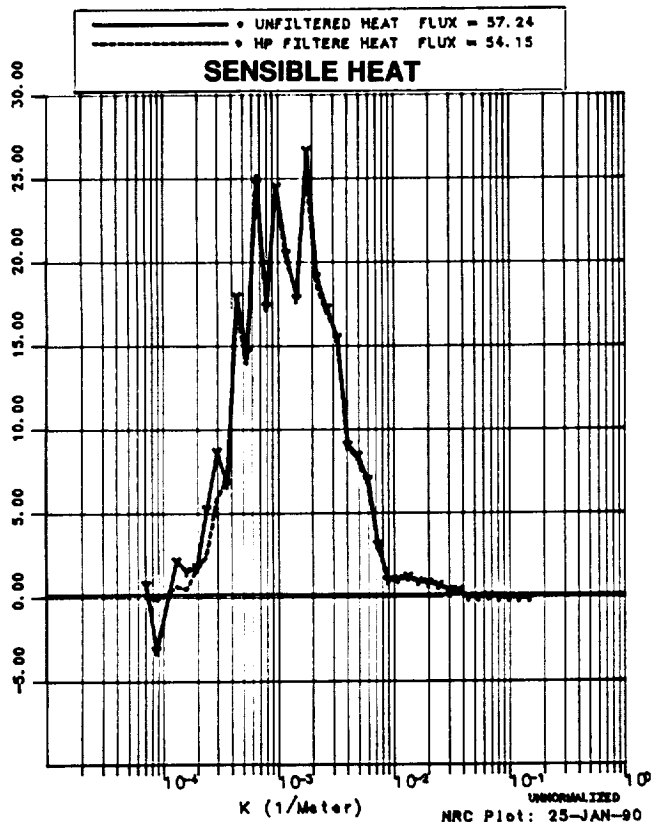
NRC/NAE TWIN OTTER COSPECTRA
FIFE 06, AUG 4 1990, DTRENDED LIT/WEP



NRC/NAE TWIN OTTER COSPECTRA
FIFE 06, AUG 4 1990, DTRENDED LIT/WEP



NRC/NAE TWIN OTTER COSPECTRA
FIFE 06, AUG 4 1990, DTRENDED LIT/WEP



NRC/NAE TWIN OTTER COSPECTRA
FIFE 06, AUG 4 1990, DTRENDED LIT/WEP

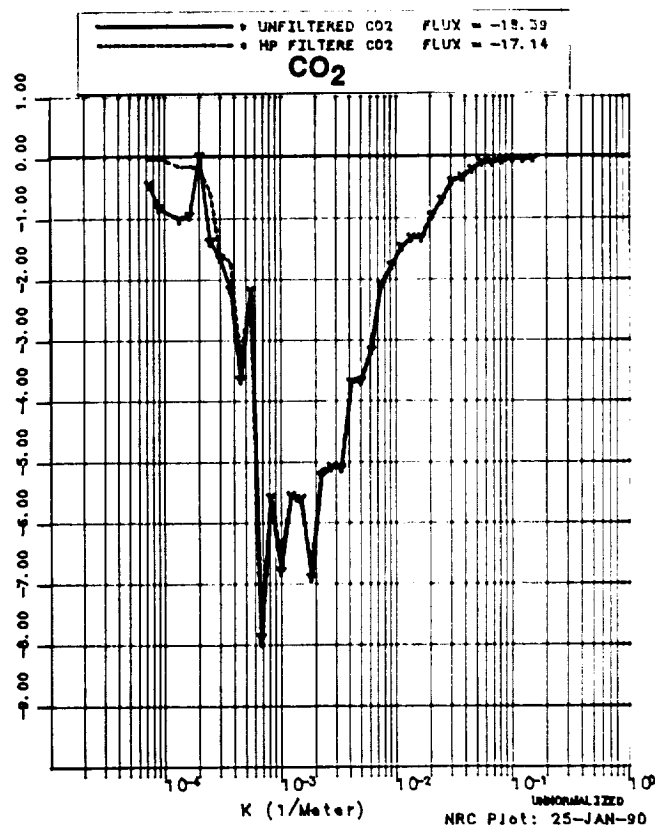
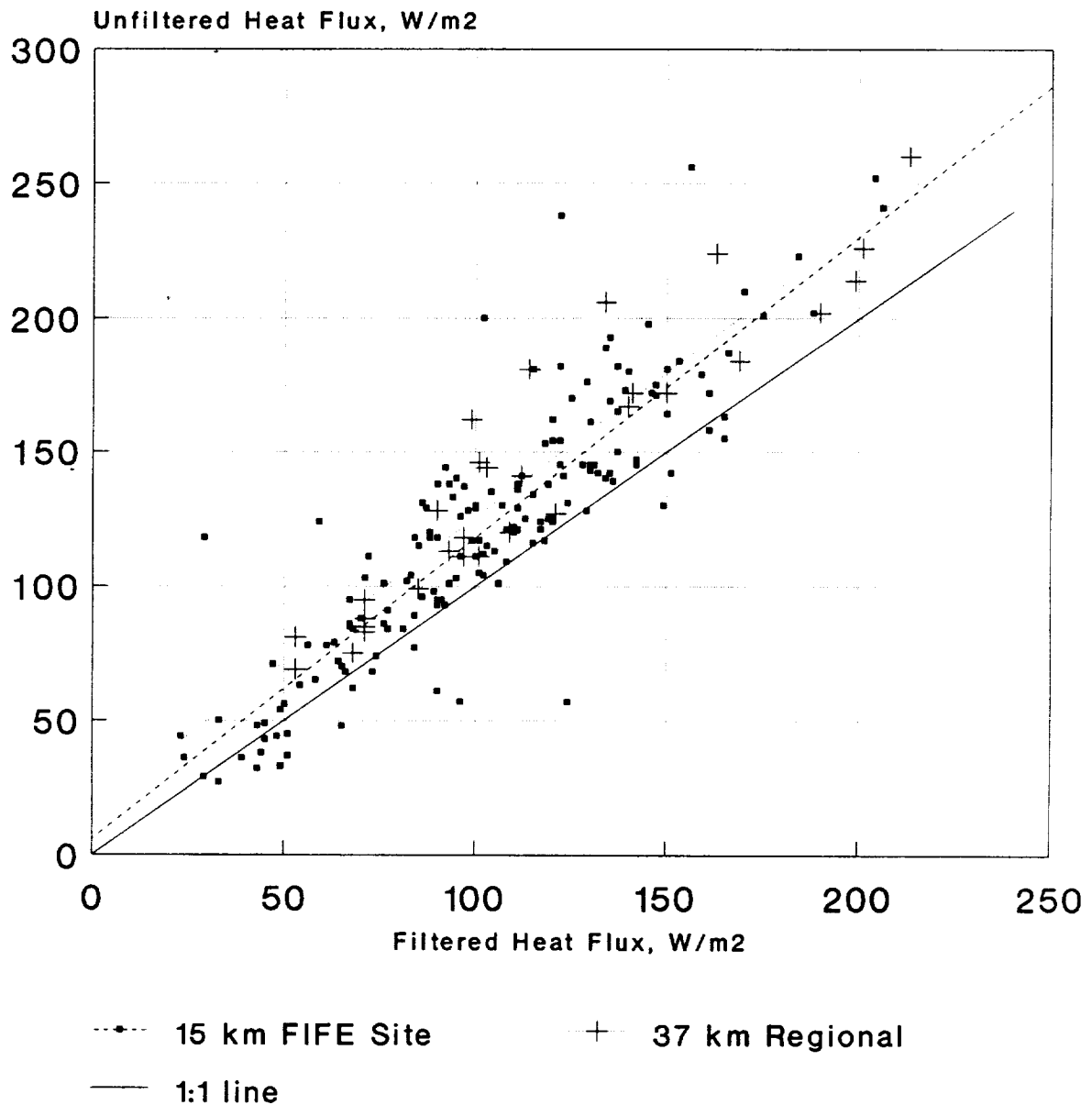


FIG. 14: EFFECT OF HIGH-PASS FILTERING

Fig. 15: Unfiltered vs Filtered Sensible Heat Fluxes - 1989



All FIFE-89 Runs below 300 m
with no large trends in temperature

AS-00219